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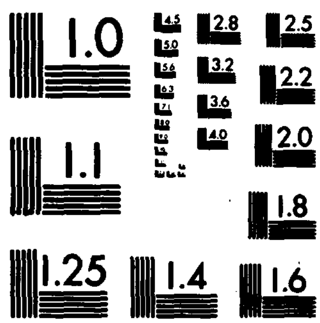

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A HEURISTIC ROUTE SELECTION MODEL FOR LOW LEVEL AIRCRAFT FLIGHT THROUGH DEFENDED TERRAIN

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MAY 1980

U.S. ARMY MISSILE COMMAND
Redstone Arsenal, Alabama 35809

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This report presents a heuristic route selection model for developing aircraft routes through hostile terrain. The capability of modern air defense systems has forced aircraft to utilize low level flight to avoid detection, thereby increasing survivability. By identifying the high and low points within an area, the model determines their exposure values, which are utilized with their height and internode distance to calculate a penalty for flying to a point from the current position. In developing a route, the model utilizes basic

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information concerning air defense deployment, initial and destination points, and terrain data to specify a minimum-exposure, minimum-elevation route.

The results include the development of routes for eight 10 by 10 kilometer areas, and six larger terrain areas varying in size from 20 by 20 kilometers to 35 by 35 kilometers. Validation shows the heuristic to be competitive with visual procedures, but at a large reduction in time.

ACKNOWLEDGEMENT

There are several people whose contributions to this research I would like to acknowledge.

I wish to thank my Committee Chairman, Dr. Richard M. Wyskida, for his assistance and encouragement given in this effort. The long discussions and penetrating reviews provided valuable insight in focusing the direction of this research.

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CHAPTER I

INTRODUCTION

1.1 Background

Throughout history man has engaged in battle with his fellow man. A review of history is a review of warfare. Man seems to have a general propensity to consider warfare a major objective in his life. The early settlers of this country encountered a formidable foe in the native Americans. The covered wagon caravans were the early settlers' attempts to minimize the Indian threat when traveling West. Further, the scouts would seek high vantage points in the terrain where they could observe and provide early warning of enemy forces and their movement.

Scientific and technological developments have provided present day man with complex equipment and devices with which to do battle with his enemies. Commonplace among this arsenal are missiles, high performance aircraft, helicopters, air defense systems, tanks, radars, submarines, and a host of sophisticated hand-held weapons including lasers. It should be noted that the radar replaces the observer on the lonely hill top, while tanks and armoured vehicles replace the covered wagons. The major difference in the two scenarios is the equipment of which aircraft, missiles and air defense systems are of concern in this research effort. It is with the concept of air defense that modeling becomes paramount, since models permit reality to be depicted for a very modest investment of time and money.

1.2 Air Defense Modeling

The effectiveness of medium and high air defense systems impose a high degree of risk to aircraft survivability when an aircraft is operating in the air space protected by these systems. This situation leaves low level flight as the only option open to the aircraft to avoid these air defenses. Aircraft are a high value resource which must be utilized wisely. Regardless of the results of the analysis, the mission has to be undertaken. The battle, and in turn the war, can only be won if one attacks. Thus, one must enhance the aircraft's probability of survival.

One means to increase the aircraft's chances of survival is to plan a route which minimizes its exposure to enemy air defenses. A terrain following route can be optimized in the vertical plane, but the initial question is where to position the ground track in the horizontal plane that the aircraft will follow. If one knew the route which minimized the exposure, then there would be an easing of the vertical constraint imposed by the air defenses [1].

The objective of this research is to develop a heuristic method for selecting a minimum-exposure, minimum-elevation route for terrain following flight through defended terrain. Considering the expensive aircraft in use today, the computer modeling of air operations on the tactical battlefield is a useful tool for assessing tactics, performance, and results.

1.3 Research Topic

If one knew the location of low exposure routes, then an assessment could be made on the expected outcome of employing these routes. The high exposure route is merely to allow the aircraft to fly within the

radar coverage. This research was undertaken to find a method which allows one to find the low exposure route from some initial point to a destination point.

A minimum exposure route will logically use terrain features to hide the aircraft from the air defense sensors. This assumption implies that low elevation areas should have a lower exposure profile than high elevation areas. It is intended to use the low elevation areas as the basic units from which a minimum exposure route can be built. Thus, a heuristic route selection model will be developed in this dissertation that achieves a minimum-exposure, minimum-elevation route for low level flight.

1.4 Outline of Succeeding Chapters

Chapter II is a review of the literature pertaining to routing, aircraft and air defense. Three documents of particular interest to this research are discussed first. The remainder of the chapter pertains to the literature in general. The tactical situation from which this research derives is given in Chapter III. The scenario is typical of a medium intensity battle. The development of the model is presented in Chapter IV. The discussion follows the solution sequence of the model.

Chapter V is an example of the model selecting an appropriate route for the prescribed conditions. The calculations are based on the material of Chapter IV. The model results are contained in Chapter VI. The results for two small terrain areas are presented first, followed by the results for a much larger terrain area.

Chapter VII is the validation of the developed model. Some of the model results are compared to manually developed, preferred routes. Finally, Chapter VIII presents the conclusions of this research and recommendations for further research.

CHAPTER II

LITERATURE REVIEW

2.1 Introduction

An intensive review of the literature identifies three research results which are pertinent to this effort. A recent dissertation by James E. Funk [2] provides a method for determining the optimal vertical flight path for a given route. The second effort was reported in The University of Alabama in Huntsville Research Institute (UARI) Report, Optimal Attack Route Selection Method [3]. The third research of interest is a Helicopter Route Selection Model developed by Ohio State University for the large land combat model DYNTACS [4]. In addition, the literature pertaining to network modeling, computer software algorithms, geology and geography, highway routing, and electronic circuit routing were investigated to determine their applicability in aircraft routing.

Modern air defense systems have the capability to deny medium or high altitude aircraft attack routes to a target. To overcome this restriction, low level flight has now become a preferred method for penetrating air defenses. Low level or terrain following flight paths, however, presents the problem of impact with the terrain. In the literature this problem is also referred to as clobber.

The ideal flight path for terrain following would be a flight curve that matches the terrain curvature by some clearance height above the local terrain. The aircraft control system limits the vehicle to flying a smooth flight path which approximates this clearance curve. Figure 2.1

is an illustration of a typical terrain profile with the clearance curve and flight path for low level flight. The slower the aircraft flies the closer the flight path can approximate the clearance curve.

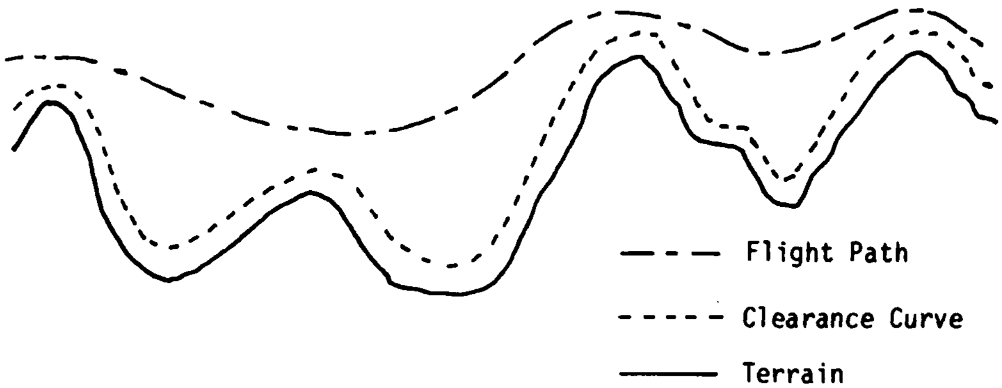

Figure 2.1. Low Level Flight Profile.

The review of unclassified documents concerning low level flight has centered on the problem of optimal aircraft control systems. Advances in microprocessors and digital electronics seem to be the controlling factor in increasing the capability of on-board flight computers and navigation systems [2, 5, 6]. With increased on-board computer capacity, real time optimization of flight profiles become possible, thereby achieving an optimal low level flight path along the selected route.

In the literature that was reviewed, a major consideration in any air defense study is terrain modeling. Terrain modeling is also utilized in such studies as highway routing and construction, pipeline routing, and land use. Most recent research in this area is directed at using computer graphics to depict the terrain in contour map form and in picture form. Existing terrain models are presently adequate for air defense modeling [7, 8, 9, 10, 11]. The terrain models, however, do not provide for aircraft route selection analysis.

2.2 Reported Research

The dissertation by J. E. Funk presents a mathematical programming method for solving the aircraft control problem in terrain following flight [2]. The first step in his approach was to construct a trajectory model which is incorporated into the objective function or, as he has defined it, the performance function. The performance function is defined in terms of an excess clearance variable. The function is optimized subject to differential constraints of height, slope and curvature of the flight path.

To provide computational ease the problem is discretized. The performance function and constraints are transformed to a matrix form which can now be considered as a quadratic or linear programming (LP) problem. This quadratic or LP problem is solved using existing algorithms. To develop a complete flight path this procedure considers overlapping segments. Segment i of the flight path is optimized and then the next overlapping segment, i+1, is optimized with the initial portion of segment i+1 defined by segment i. Since the discrete segments overlap, the resulting flight path is continuous and there are no discontinuities at the boundaries.

In Funk's research, only the vertical terrain avoidance is examined, and not the lateral terrain avoidance. His results give a solution to the aircraft control system to yield the optimal flight path over a given terrain route.

In the UARI report, a dynamic programming approach for determining optimal attack routes is presented [3]. Although this work was performed several years ago, it is still current with techniques recently reported. The backwards solution method was employed to evaluate the recursive function.

The route selection process that was developed is a direct application of dynamic programming. To represent the multi-stage decision process, a grid network was used where each grid point is equivalent to a stage in the decision process. Thus, the optimal decision path is the optimal attack route.

The probability of survival, (P_s), is the return at each stage. The optimal path has the highest probability of survival or is the least risk route. The probability of survival at a grid point is given by:

$$P_s = (1 - P_k).$$

The probability of kill (P_k) for an air defense site is the resultant of the probabilities of acquisition, tracking, missile launch, missile flight, and warhead lethality.

Two recommendations for further research in this report were of interest. This technique had only been applied to small scale problems, and further research on large scale problems with multi-attackers and multi-radar sensors were suggestions for consideration. Also, it was recommended that network techniques such as shortest path or least cost path be considered.

The Helicopter Route Selection Model that has been developed is another method using dynamic programming [4]. This model is an adaptation of the ground unit route selection model that is a subroutine of DYNTACS X. The first step is to determine the intervisibility areas for each weapon. These areas define the masked and unmasked portions of the battlefield. From the set of masked areas a series of concealed areas in close proximity to one another can be connected to form an avenue of approach. Having identified this avenue the route can be selected that follows the general shape of the approach corridor.

Up to this point all analyses of intervisibility and terrain have been performed outside of the actual model. With the process completed the route corridor is defined in the model. The intervisibility areas are defined by a set of irregular convex shapes having straight line boundaries between each vertex. Along each boundary one or more points define the possible beginning (or end) of a route segment across the convex shapes (Figure 2.2). These points are shown as circles on Figure 2.2 and are also entered into the model as data.

With the terrain area thus described for the model, the route selection routine can be utilized. A series of nine points that are in the direction of attack are selected for route analysis. The selection routine evaluates these boundary points identified by the probability of survival at each point. The point with the highest probability of survival is selected and then the next series of nine points along the route corridor are considered. This process is the forward solution method for dynamic programming problems.

2.3 Open Literature

One of the first areas in the open literature to be investigated was cluster analysis. An excellent presentation of cluster analysis can be found in Anderberg's text [12]. When data has no discernible pattern, cluster analysis can provide a tool to uncover the pattern. Hierarchical clustering is widely utilized to develop the linking of data as each entity is processed. In this research, the idea of nearest neighbor and centroid of a cluster that is used with non-hierarchical clustering, are utilized as a basis for processing the terrain data.

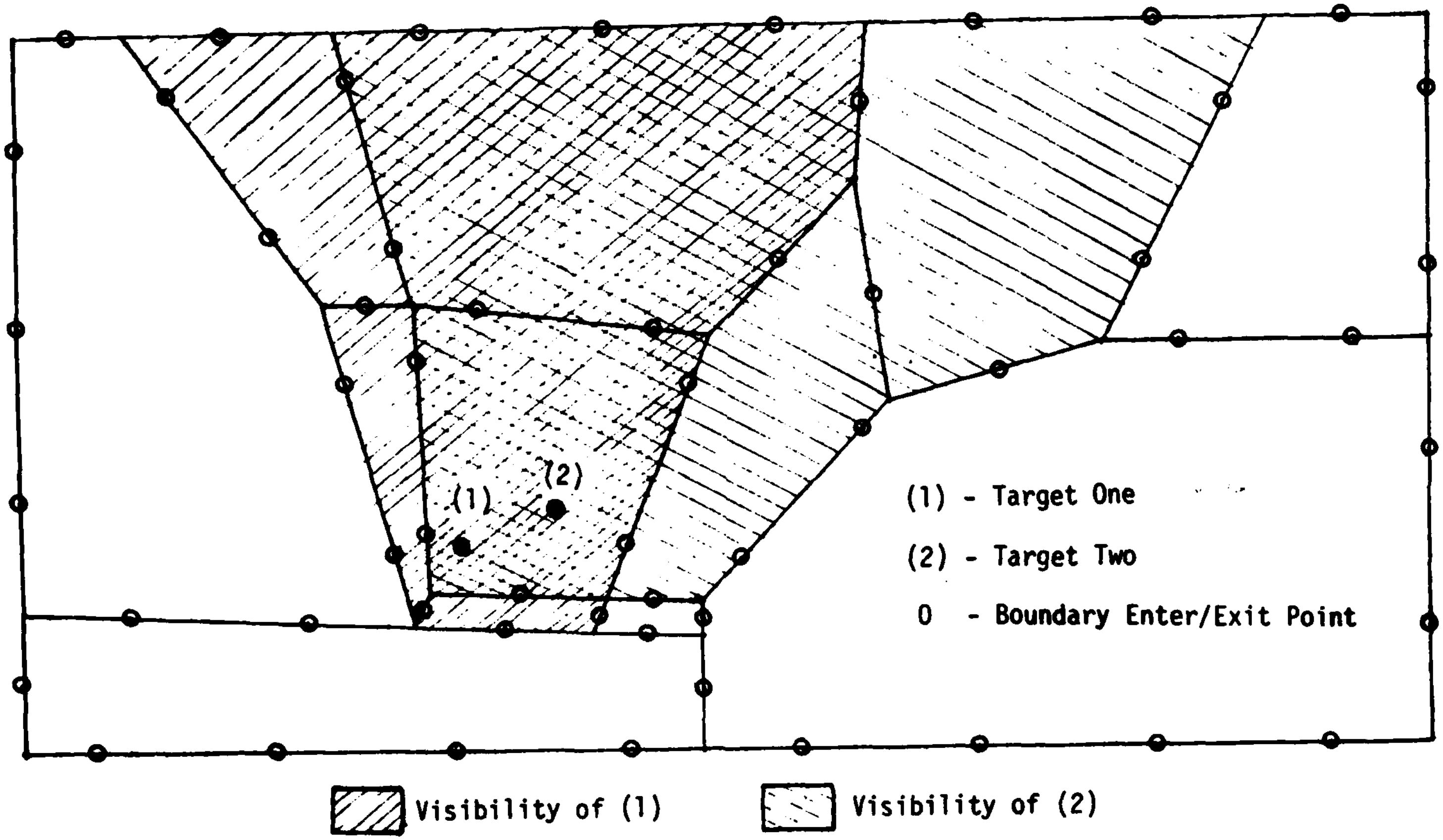

Figure 2.2. Partitioned Terrain Area.

For a data set of N observations, clustering into subsets of like values indicates an association or similarity for the cluster membership which is not shared by those outside that cluster. Typically, the members of a cluster will minimize some criterion such as minimal distance from the mean of the cluster. The mean of a cluster can be utilized as the centroid. For the total data set of k clusters, membership in cluster i can have a point to centroid distance different from cluster j, which would indicate an individual cluster density. Thus, a higher order clustering can be performed on the initial clusters because their centroids are now the data points. The centroids of the first order cluster can be weighted according to density and be the point used as the value for the higher order clustering.

Clustering methods are means by which data can be grouped, associated, or placed in some classification scheme for analysis. There is no one preferred method to be used, as several methods normally need to be used to determine if there is any pattern or intelligence to be derived from the data.

The aircraft routing problem can be formulated as a network or a graph problem. In the literature, the theoretical aspects of a network are referred to as graph theory, whereas the practical aspects are known as network analysis. A highway network connecting cities would be vertices for the cities and edges for the highways when related to graph theory. Networking would refer to the cities as nodes and the highways as arcs. Depending on the reference, the terminology for the cities could also be called junction points, intersection points, or simply points; and likewise, an arc could also be a branch, link, path or line.

For a network or graph G there is a collection of points x_1, x_2,..., x_n (denoted by the set X), and a collection of lines a_1, a_2,...,a_m (denoted by the set A) which join some or all of these points. The graph is described and denoted by the doublet G(X,A) [13]. An edge joining x_i with x_j is denoted by $[x_i, x_j]$.

In network analysis and cluster analysis there are three distance measures that are of interest. First, the standard Euclidean distance or metric for two points in space is given by:

$$d = \left[(x_2-x_1)^2 + (y_2-y_1)^2 + (z_2-z_1)^2\right]^{\frac{1}{2}} .$$

Second, in many location problems, especially in urban areas, travel is along an orthogonal set of streets. Travel which is restricted to directions parallel to the coordinate axes use a rectilinear or Manhattan metric that defines distance between two points (x_1, y_1) and (x_2, y_2) by:

$$\left|x_1-x_2\right| + \left|y_1-y_2\right| .$$

The rectilinear metric could have been used in the UARI Optimal Attack Route Method since travel was restricted to grid lines. Third, when travel is restricted to take place on a network, then the internode lengths are the distance measure [14].

The above concepts were utilized in developing the approach to the route selection process for low flying aircraft. The ideas of nearest-neighbor and cluster centroid form the bases for the terrain data reduction.

CHAPTER III

PROBLEM FORMULATION

3.1 Tactical Scenario

This research considers an area of air defense war gaming. There are two basic situations that a tactician can analyze. In one case, the tactical situation is portrayed from the defender or air defense site aspect. For the other case, the tactical situation is presented from the attacker or pilot's viewpoint. The specific problem this research addresses is that of selecting a route which a low flying aircraft can use to penetrate the air defense coverage, while at the same time minimizing the aircraft exposure to these defenses. Low flying aircraft ordinarily fly within 200 meters of the terrain.

The defender desires to allocate his air defenses in a pattern to achieve maximum coverage. The sensors (radar, infrared, or visual) are positioned in the terrain to be defended such that visibility is maximum in the principle direction the site is responsible for protecting. In actual terrain there can be certain azimuths for which coverage is marginal or non-existent. To ensure that the total area is covered, the air defense sites are situated so that individual site visibilities overlap each other thereby providing a pattern with total coverage. Thus, any portion of the total area is being covered by one or more air defense sites. The attacker is faced with the situation of attempting to select a route which avoids these sites and maximizes his survival while reaching the target, and accomplishing the mission.

Along with terrain following, there are some other options the tactician can choose to enhance the aircraft and pilot's survivability. The attacker can use electronic countermeasures (ECM), better known as jamming. An anti-radiation missile (ARM) could be fired at each radar. Decoys or remotely piloted vehicles (RPV's) could be utilized to saturate the skies so that an aircraft can be hidden among the RPV's. To reach the primary target, a preemptive raid could be made against the air defenses. Of course, the defender is fully aware of these and other methods that can be employed to negate the air defense's ability to engage the attackers.

3.2 Aircraft Route Selection

In this research, the air defense situation is a heavily defended 35 by 35 km area through which a helicopter force must penetrate. The air defense sensors are assumed to be deployed within this region such that maximum coverage exists.

Using military terminology, the line of battle between two forces is known as the forward edge of the battle area (FEBA). The helicopter force is flying a terrain following flight path from their base across FEBA to raid an enemy rear area base. The enemy air defense sensor capability is assumed to have good low altitude coverage for a 10 km radius and good long range coverage for medium and high altitude.

In performing this raid, the objective is to traverse the whole route undetected, thus preserving the element of surprise in the attack. The air defense sensors are not being attacked or jammed in this raid. In an attempt to obscure the helicopters' approach to the target, the mountains and hills would be utilized as a mask. Intuitively, the best low level aircraft route would follow the lowest terrain. To offset this

tactic, the enemy will position some air defense sites to cover low altitude corridors into his area.

The interaction of these tactics results in the helicopter route selection being that of finding the low level route which has the fewest air defense sites covering it. Thus, a route is a linkage of several low level path legs into a continuous path that will allow the aircraft to avoid detection.

3.3 Sensor Coverage

With low altitude targets, radar sensors have clutter problems when receiving the return signal. There can be a high level of noise because of ground objects and terrain features which tend to obscure any targets that may be nearby. Any aircraft operating in an area with opposing air defenses will attempt to fly as low as possible so as to be in the clutter of the radar return signal. However, the faster the aircraft speed the higher it must fly to be responsive to the pilot's terrain avoidance commands. Thus, the aircraft pilot has two conflicting constraints; first, the aircraft must fly no higher than X meters to avoid detection, yet, second, it must fly at least Y meters above the terrain to maintain a clearance altitude. A major problem exists for the pilot when Y is greater than X.

The degree of coverage a radar site possesses from a given location is dependent on the target altitude and the local terrain. An aircraft at 50 meters altitude is more likely to be detected than an aircraft at 20 meters altitude. To graphically illustrate sensor visibility, a series of actual coverage diagrams for three sites were made at target altitudes of 20 and 50 meters. Penetrating aircraft are assumed to be approaching the sites from the west (left edge of figures). Coverage diagrams are

generated using a computer routine that generates the visibility from a site to the target altitude for 0 to 360 degrees in azimuth.

The first site, Figure 3.1, has excellent coverage to the west at each altitude. For increasing target altitudes only a small improvement in visibility is obtained. Visibility for a 10 km radius at 20 meters target altitude is 28.02 percent of the total area. At 50 meters, visibility is 31.85 percent.

In Figures 3.2 and 3.3, the site has good coverage at each altitude. At 20 meters target altitude, visibility is 29.85 percent and improves to 43.10 percent at 50 meters. The prominent direction of coverage is west, but this site also has some coverage to the east.

Lastly, in Figure 3.4, a poor site location is shown. Visibility at this site varies from 5.31 percent at 20 meters to 8.63 percent at 50 meters. Coverage provided by this site is southerly.

These three site locations are deployed in the same area and the composite coverage is shown in Figure 3.5. In the overall coverage, the poorly situated site provides sensor detection to the south which the other sites lack. Thus, the poor location is better than expected because it furnishes satisfactory coverage when considering the combined coverage.

As can be seen in these series of figures, the coverage of an area by air defense sensors limits the ability of an aircraft to penetrate the area undetected. The deployment of several air defense sites imposes a visibility constraint on the selection of routes through the area. It may be impossible to find an undetectable corridor.

3.4 Terrain Data

The terrain data base used in this research is Defense Mapping Agency (DMA) terrain data which provides the height above sea level for

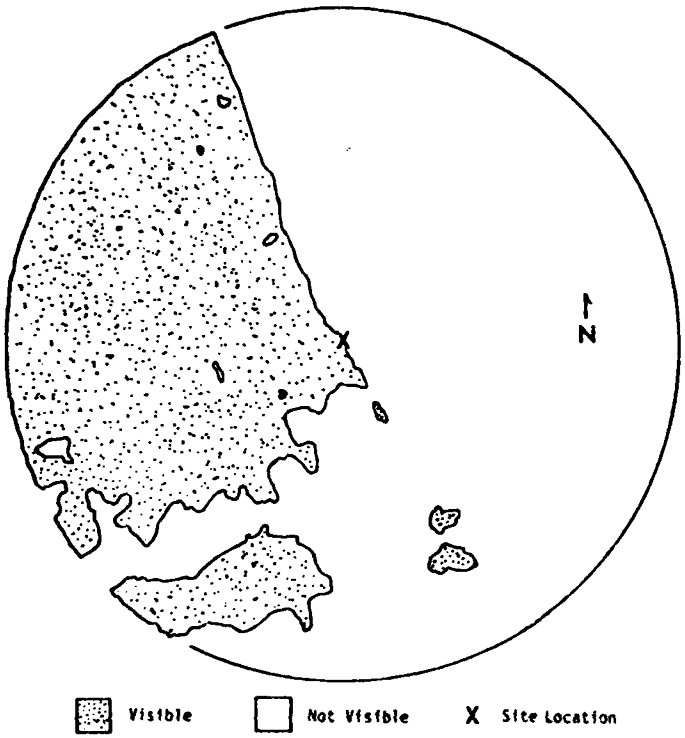

Figure 3.1 Site 1 - Target Altitude 20 Meters, Visibility 28.02%

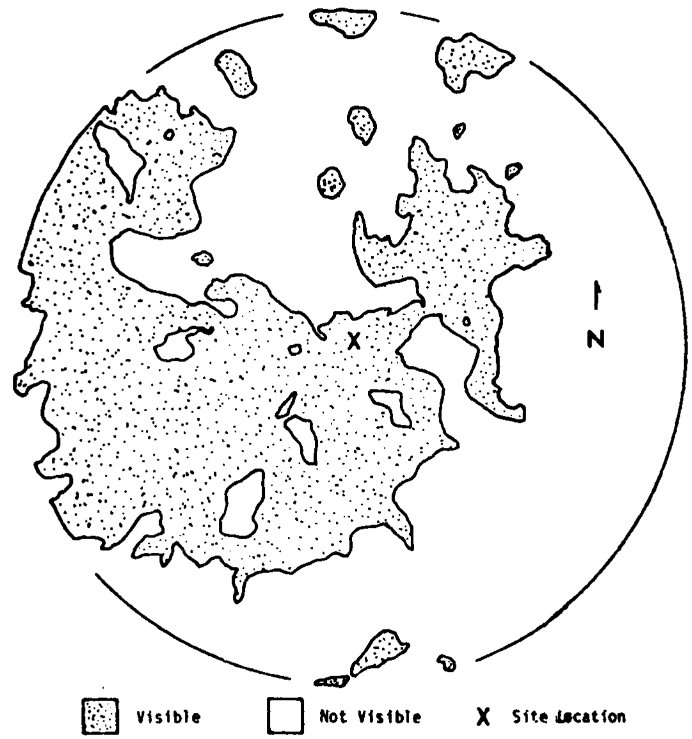

Figure 3.2 Site 2 - Target Altitude 20 Meters, Visibility 29.85%

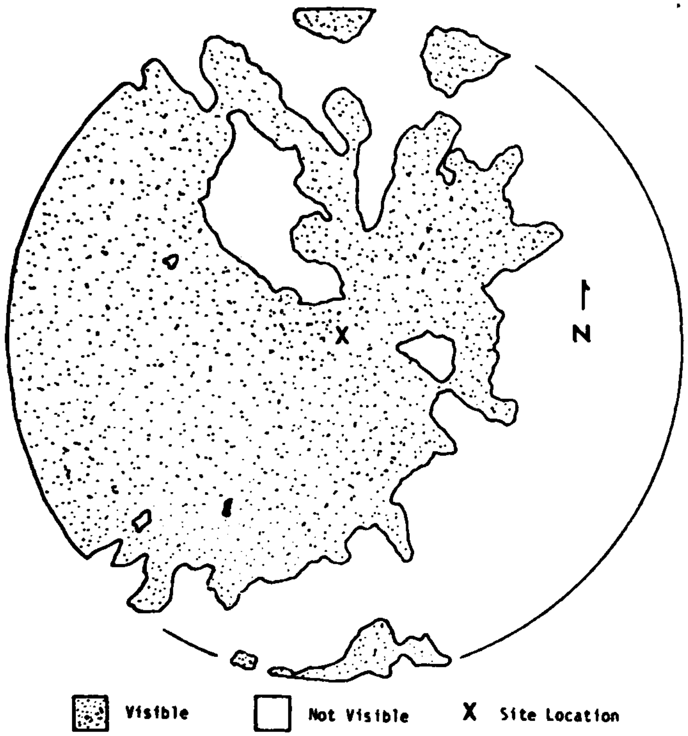

Figure 3.3 Site 2 - Target Altitude 50 Meters, Visibility 43.10%

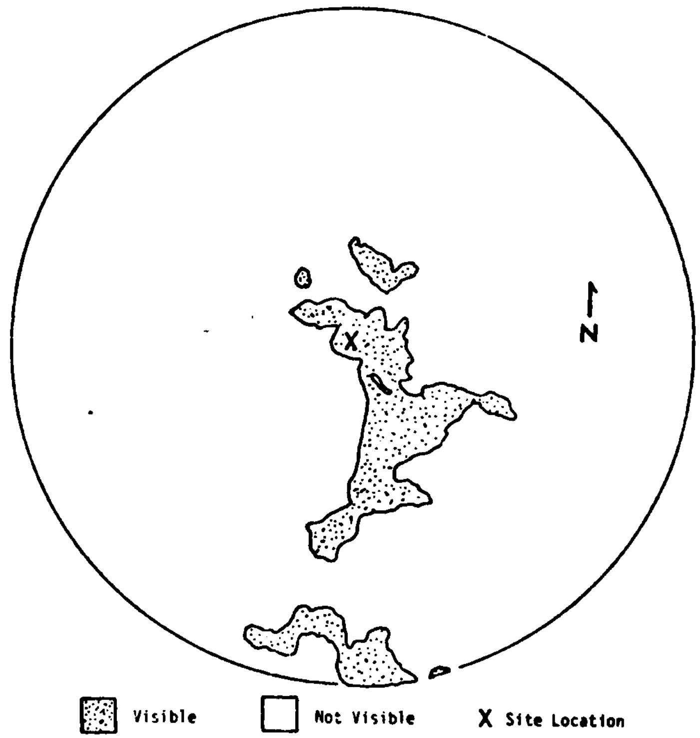

Figure 3.4 Site 3 - Target Altitude 20 Meters, Visibility 5.31%

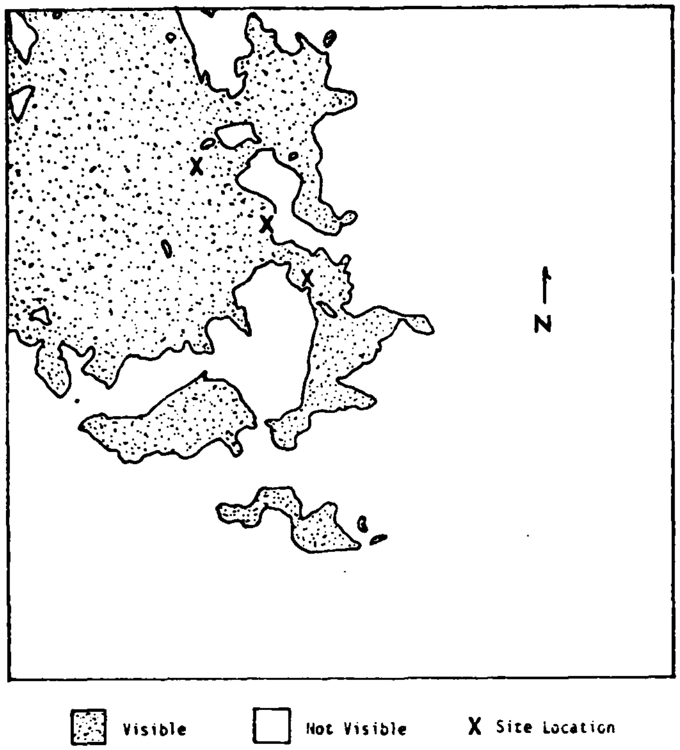

Figure 3.5 Composite of Sites 1, 2, and 3, Target Altitude 20 Meters

each terrain location. A granularity of 70.0 meters was selected in utilizing the data base. A problem with this fine a grid is the quantity of data points for even a moderate size area. For a 20 by 20 km area, this density results in 90,000 entries.

The first requirement in utilizing this data is to convert from a packed format into an array format of unpacked terrain points. The geographical area selected requires a 525 by 525 array (35 by 35 km). Since this array is too large for efficient computer processing, the area was partitioned into smaller arrays of 15 by 15. This arrangement results in a strip of 35 arrays to cover the north-south direction and 35 strips in the east-west direction (Figure 3.6). A map sheet is 15 data points from west to east, and 35 arrays of 15 data points from south to north.

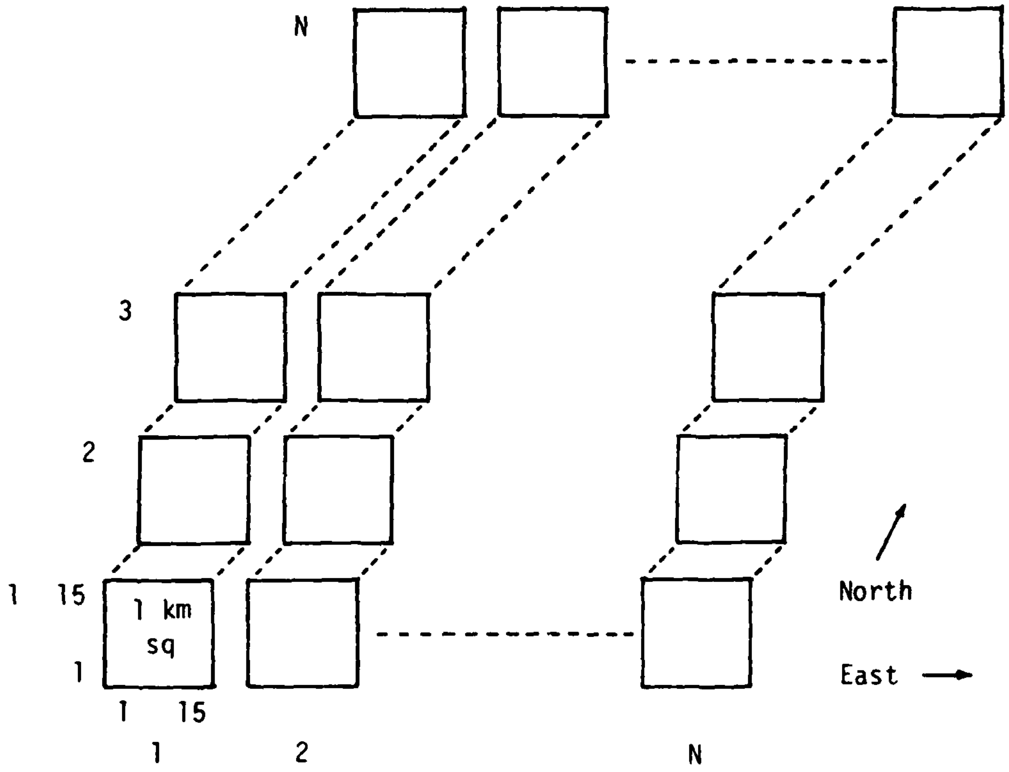

Figure 3.6. Terrain Data Arrays.

Once the terrain data is available from the conversion processing, some assumptions need to be made relating the data to the route selection problem. The premise that the aircraft route will follow the valleys and low areas requires that the low elevation terrain be identified from the terrain data. Thus, it is assumed that by a grouping or clustering process, these low elevation areas can be found. Also, the partitioning of the area allows for identification of local minimum altitudes rather than a single global value.

An example of terrain data arrays is shown in Table 3.1. As can be seen in this table, the variation in the point to point values can be stratified. Once the data is grouped into elevation intervals (or bands), the terrain relief is shown as plateaus with the lowest plateau being the lowest elevation area. The lowest stratum is a cluster of lowest terrain points from which the cluster center can then be used as a node point in the routing network.

With the terrain data analyzed and the node points established, the route can now be developed. The terrain route for the helicopter has only two known points at the onset - the initial point and the terminal point. All intermediate route points need to be selected from the nodes.

Table 3.1 Elevation Array

349	349	349	349	349	349	349	349	359	368	376	384	397	399	399
349	349	349	349	349	349	349	349	359	367	376	384	399	399	399
349	349	349	349	349	350	350	349	355	364	373	393	400	398	399
349	349	349	350	350	349	349	350	353	360	369	386	395	400	399
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345	345	344	343	344	345	345	347	349	357	367	377	387	398	398
342	342	341	341	342	343	343	345	347	349	357	368	380	400	398
338	338	338	338	339	341	342	343	345	347	350	363	374	396	399

CHAPTER IV

MODEL DEVELOPMENT

4.1 Introduction

The route selection development begins with the basic terrain elevation data and ends with the minimum-exposure, and minimum elevation route. The model consists of several logical divisions that progressively solves this problem.

Initially, the model groups the terrain data into elevation bands from which cluster centroids (or centers) are developed. These centers become the node points for a routing network. Around a route node a neighborhood of node points is selected as possible links to this node. In this neighborhood each point has an exposure value which is a function of its visibility to enemy sensors, its altitude, and its distance from the node point. The exposure value is a penalty for the use of this point. Each linkage is a path or leg of the route, and all the linked nodes form a route connecting the minimum-exposure, and minimum-elevation points. The resulting path between the initial and final nodes provides a route for a penetrating low flying aircraft.

4.2 Clustering of Terrain Data

To group the terrain data into elevation bands the integer arithmetic feature of Fortran software is exploited. When arithmetic operations are performed on integer numbers, only the integer portion is

retained and the decimal portion is discarded. The following relation is utilized:

$$NE = (((E - 1)/INT)\ INT) + INT$$

where NE = the new elevation value,

E = the old elevation value,

INT = the band interval.

This calculation results in all elevation values within an INT interval of each other being assigned the maximum value of that interval. The process is identical to class intervals utilized in constructing a frequency table in statistical analysis. Instead of using the midpoint of the interval, the maximum in the class interval is used.

Once all the terrain data is stratified, then clusters of both high and low elevation points can be found. Each array of 15 by 15 covers an area of 1050 by 1050 meters. Within this area at least one low elevation cluster is identified along with a high elevation cluster. There are some cases where the whole array represents level terrain and the array consists of the same elevation values. When this situation occurs, it is necessary to check adjacent arrays to determine if this terrain is a low elevation cluster.

Since more than one low elevation cluster can occur in an array a method was developed to determine if two points were adjacent to each other. For a square grid a single point I has eight points around it as shown in Figure 4.1. The points labeled A through Q (less I) form a ring around the numbered points and cannot be adjacent to the point I.

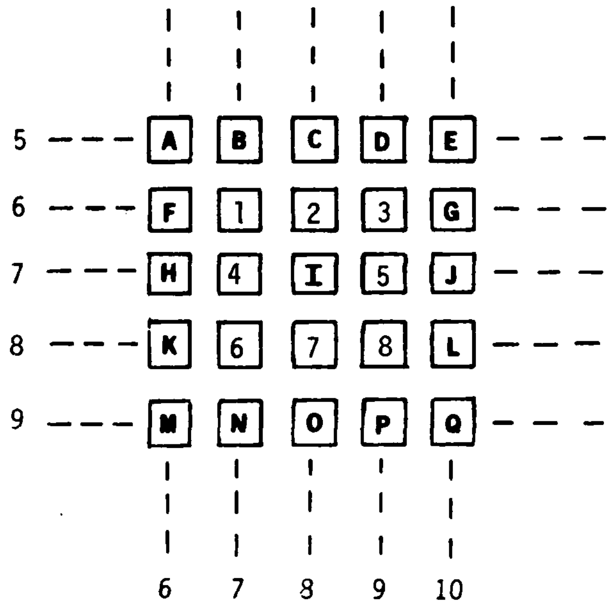

Figure 4.1 Points Adjacent to I

The array is processed sequentially by searching across each row; therefore, cluster membership is identified in order of occurrence from the beginning of the array. For example, assume that a cluster consists of the following points - I, 5, J, 7, 8 and P. These six points are a cluster located in the 15 by 15 array. The clustering procedure identifies all points of the same elevation by entering their position into a list. The indexes of a point are combined by letting INDEX = 100 (IROW) + JCOL, where IROW is the row index and JCOL is the column index. This coded number is the location of the point within the array.

In this example, let the point I be in row 7, column 8. The stored INDEX value for I is 708. The other cluster membership values are given in Table 4.1.

Table 4.1 Cluster Membership

Member	INDEX Value	I-Difference
I	708	0
5	709	1
J	710	2
7	808	100
8	809	101
P	909	201

When searching this list for cluster membership the value of INDEX provides a means to separate clusters. Since the membership is sequential, only those points occurring after I need to be examined (points 5, 6, 7 and 8). By subtracting INDEX values the difference indicates adjacency.

For a point to be adjacent to I the difference must be either 1, 99, 100 or 101; any other value indicates that the point is separated by one or more rows (or columns). Points 5, 7, and 8 are identified as belonging to the same cluster as point I before considering the next point in the list. When point 5 is evaluated, point J is placed in the I cluster. The evaluation of point J does not add any new points to the cluster since all points adjacent to J are already in the cluster.

Point 7 evaluation adds the last point P to the cluster. This subtraction method is a quick process for identifying adjacency.

After determining which points are in the cluster, a center or centroid of the cluster can be calculated. Since the data points are planar, then each cluster has a centroid that is defined by the mean values for X and Y within the cluster:

$$(\bar{X},\bar{Y}) = \left(\sum_{i=1}^{n} \frac{x_i}{n} \quad , \quad \sum_{i=1}^{n} \frac{y_i}{n} \right)$$

The centroids are now used as node points in the route selection process. The centroids are separated into two groups. If the centroid is for a low elevation cluster, it is placed in a *low elevation array*. Likewise, centroids for a high elevation cluster are placed in a high elevation array. The centroids in the high elevation array are identified by a minus sign. Figure 4.2 gives the location of the low and high elevation centroids that were found in the 10 by 10 km area utilized in the model development.

4.3 Sensor-Node Line of Sight

A major consideration in selecting a tactical aircraft route is to ensure that the route avoids enemy air defenses as much as possible. To determine the degree of visibility along a route, each centroid has to have its line of sight (LOS) to each sensor determined. The result of this determination is an exposure value associated with each node point.

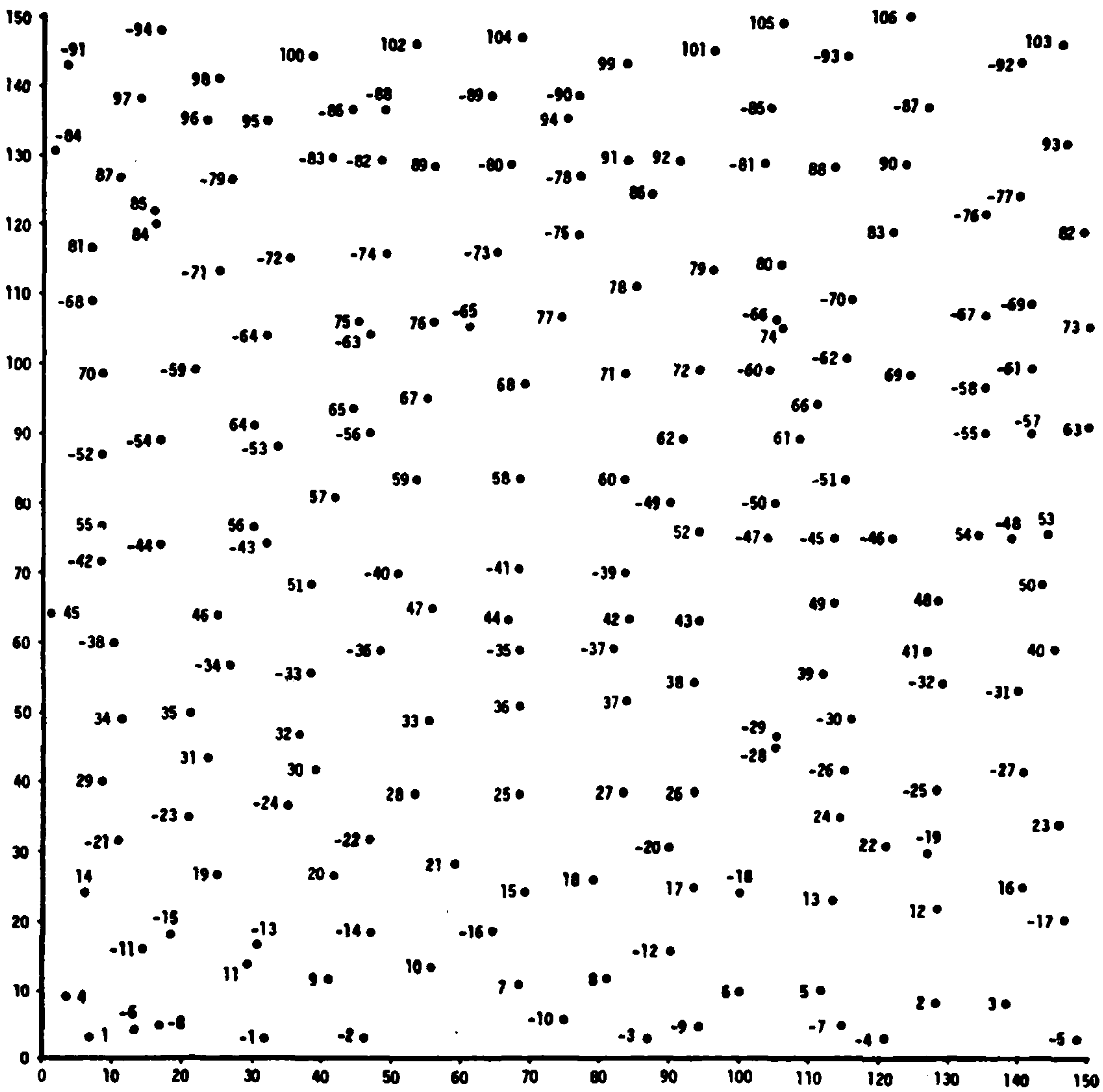

Figure 4.2 High and Low Nodes for Area One

To calculate the exposure value of a node point, the range between the node-sensor combination, together with the number of sensors, is required. The further a sensor is located from the node, the less of a threat it is since the probability of kill (P_k) is partially a function of range. However, the number of air defense sites having visibility to a point will increase the P_k. Since the sensors will tend to be deployed behind and along the general flow of the main battleline, an average range to sensors was selected as an exposure value. The exposure value is given by:

$$EP = NS \cdot \left[\frac{R_{max} - \dfrac{\sum_{S=1}^{NS} R_{Sj}}{NS}}{R_{max}} \right]$$

where EP = the exposure value for node j with all sensors that have LOS with this node,

NS = the number of sensors that have LOS with node j,

R_{max} = the maximum node-sensor separation that exists for all node-sensor combinations,

R_{Sj} = the distance between the sensor and node j.

The value EP is calculated for all node-sensor combinations for both high and low elevation. As the route is being developed, the exposure values for the nodes are used as part of a penalty function. This discussion of the route selection is deferred to the next section.

For large areas of terrain, the data base has to be analyzed in segments or subareas that remain within computer core capacity. To satisfy

this restriction requires a bookkeeping method of array pointers to record the progress of the LOS calculations and which node-sensor pairs have been completed.

Referring back to Figure 3.6, the partition of the terrain data base is shown. Figure 4.3 presents the basic planar relationship between two nodes and a sensor. The + indicates the boundaries between each array of 15 by 15 terrain data points. Within this base the terrain elevation points represent X - Y coordinates of a square grid system. The vector between the node and sensor will intersect these grid lines and the array boundary lines. Along the X-axis the array boundary lines are also the map sheet boundary lines. Each intersection point of the vector and grid line is within 35 meters of a known elevation point. This known point is checked for masking of the node from the sensor. If masking occurs, the processing of this vector (or radial line as it is called in the air defense literature) is complete and the next node-sensor combination is processed [15]. If LOS exists at this intersection point, then the routine steps out of the vector to the next intersection. When the sensor location is reached and no masking terrain point has been encountered, then LOS exists between the node point and the sensor. The number of sensors which can see this node is then incremented by one.

To know which terrain point is along the LOS vector, the array indices are calculated from the vector-grid line intersection. The map sheets are read from west to east; therefore, all node-sensor vectors are oriented from west to east to allow one pass through all the data. In the model, the map sheet boundaries are named after the compass directions -

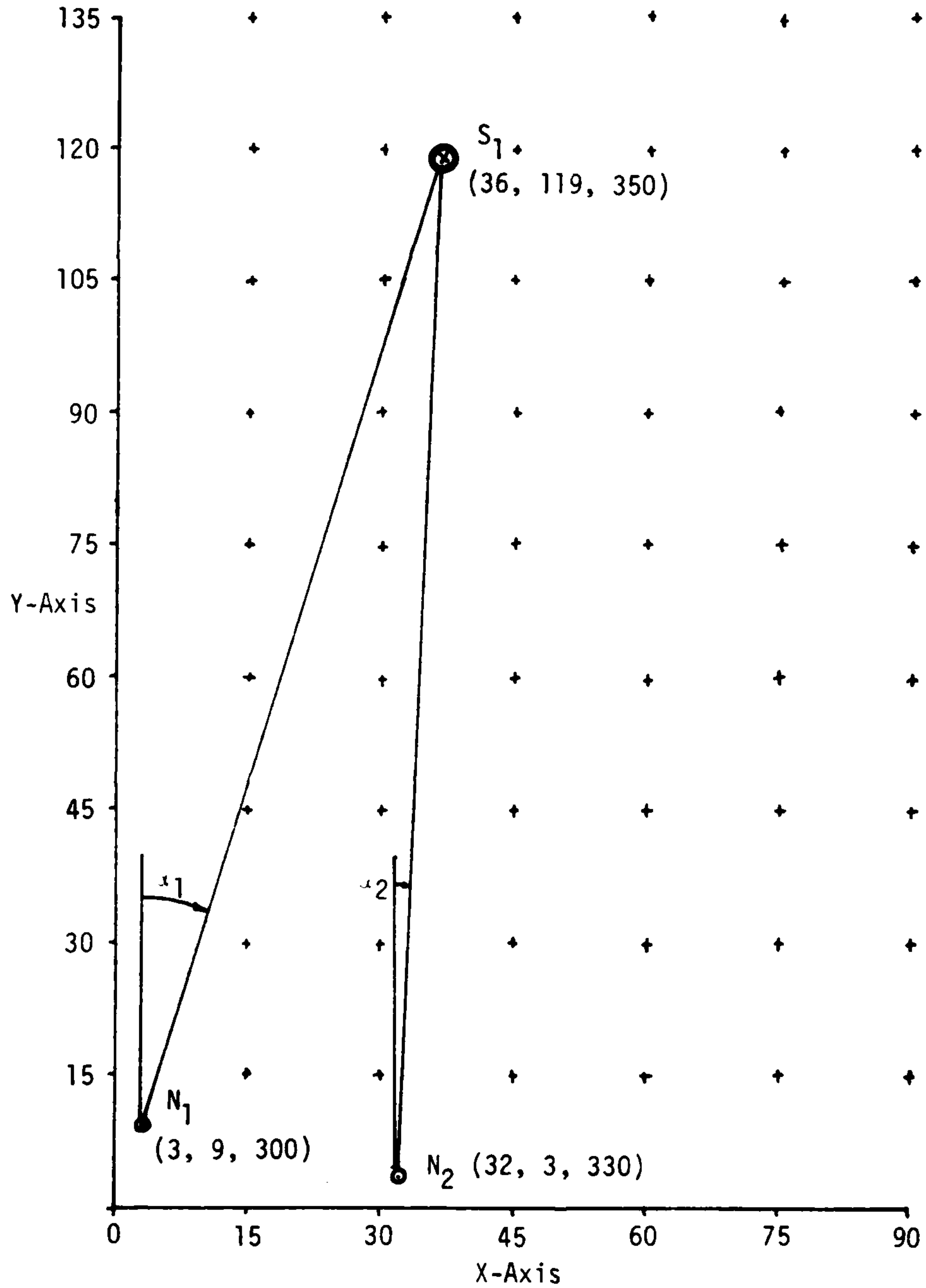

Figure 4.3 Sensor-Point Locations (X, Y, Z)

EAST, WEST, NORTH and SOUTH. As each map sheet is read, the previous EAST becomes the current WEST.

In Figure 4.3 the node point N_1 (3, 9, 300) and sensor location S_1 (36, 119, 350) define the end points of the vector $N_1 S_1$ with an azimuth angle α_1. The other node-sensor vector is $N_2 S_1$ with an azimuth angle α_2. The location of terrain points along these vectors becomes a trigonometic problem. The parameters defined below provide the indices needed to extract the terrain points from the data base.

$$d = \left[(x_2-x_1)^2 + (y_2-y_1)^2 \right]^{\frac{1}{2}}$$

$$\cos\alpha = (y_2-y_1)/d$$

$$\sin\alpha = (x_2-x_1)/d$$

$$\text{Comp } x = \begin{cases} 1 & , X_1 < \text{WEST} \\ (X_1 - \text{West})+1, & X_1 > \text{WEST} \end{cases}$$

$$\text{Left Comp } y = \begin{cases} \cos\alpha\ ((\text{WEST}-X_1)/\sin\alpha), & x_1 < \text{WEST} \\ 0 & , x_1 > \text{WEST} \end{cases}$$

where: d = the magnitude of the vector,

cos α = the cosine of the azimuth angle,

sin α = the sine of the azimuth angle,

Comp x = the x-axis component of the vector within the map sheet,

Left Comp y = the y-axis component of the vector for the West boundary.

From these parameters the row and column indexes can now be determined. For a vector, the indices are given below.

$$\text{COLUMN (x-axis)} = \begin{cases} x+\Delta x & , |\sin\alpha|>\sin 45^{o} \\ (\Delta y/\cos\alpha)\sin\alpha + x & , |\sin\alpha|<\sin 45^{o}, x>\text{WEST} \\ (\Delta y/\cos\alpha)\sin\alpha + x - \text{WEST}+1, & |\sin\alpha|<\sin 45^{o}, x<\text{WEST} \end{cases}$$

$$\text{ROW (y-axis)} = \begin{cases} y + \Delta y & , |\sin\alpha|<\sin 45^{o} \\ (\Delta x/\sin\alpha)\cos\alpha+y & , |\sin\alpha|>\sin 45^{o} \end{cases}$$

The final value of the row index has to be transformed to indicate which array on the map sheet is the correct one. Thus, the final row index is given by integer arithmetic.

$$\text{ARRAY} = (\text{ROW} - 1)/15$$

$$\text{ROW} = \text{ROW} - (\text{ARRAY}-1)(15)$$

The terrain data located at (ROW, COLUMN, ARRAY) is checked to determine if its elevation will block the LOS. If it does not mask the node, the indices are incremented to the next value to be evaluated. After all node-sensor combinations have been processed, the route development can begin.

4.4 Route Selection.

With the node points for a route and their visibility determined, the method for linking these nodes into a route can be finalized. Two other characteristics of a node need to be considered along with its visibility. The first is its elevation in relation to surrounding nodes and the second is the distance to these surrounding nodes.

To determine the area size that should be considered a neighborhood about a node, several military helicopter pilots were contacted to discuss terrain following or nap of the earth flying. These pilots unanimously report that a range of one kilometer is utilized to consider their next position. Even though major terrain features used for reference points can be seen several kilometers away, terrain following flights require a pilot to concentrate on the immediate area to avoid terrain impact. Therefore, one kilometer was selected as the rectilinear distance about a node to define a neighborhood.

Depicting the relationship of nodes in a neighborhood, Figure 4.4 contains the nodes surrounding nodes 13 and 17. These nodes are in the neighborhood of either 13 or 17. Table 4.2 lists these nodes, the coordinates, and the distance from the center (1 unit = 70 meters). The negative nodes are the high elevation centers and the positive nodes are the low elevation centers. As can be seen in Figure 4.4 and Table 4.1, five nodes are shared by nodes 13 and 17.

With this information, a value can be assigned to these neighborhood nodes based on their elevation and distance from the primary node. The higher elevation nodes would normally be avoided in favor of traveling to a low elevation node. A penalty for height is added to the exposure value of each node by the following factor.

$$ZP_j = \left(\frac{Z_j - Z_{min}}{ZR} \right)$$

where ZP_j = the penalty assigned to node j ,

Z_j = the elevation of node j ,

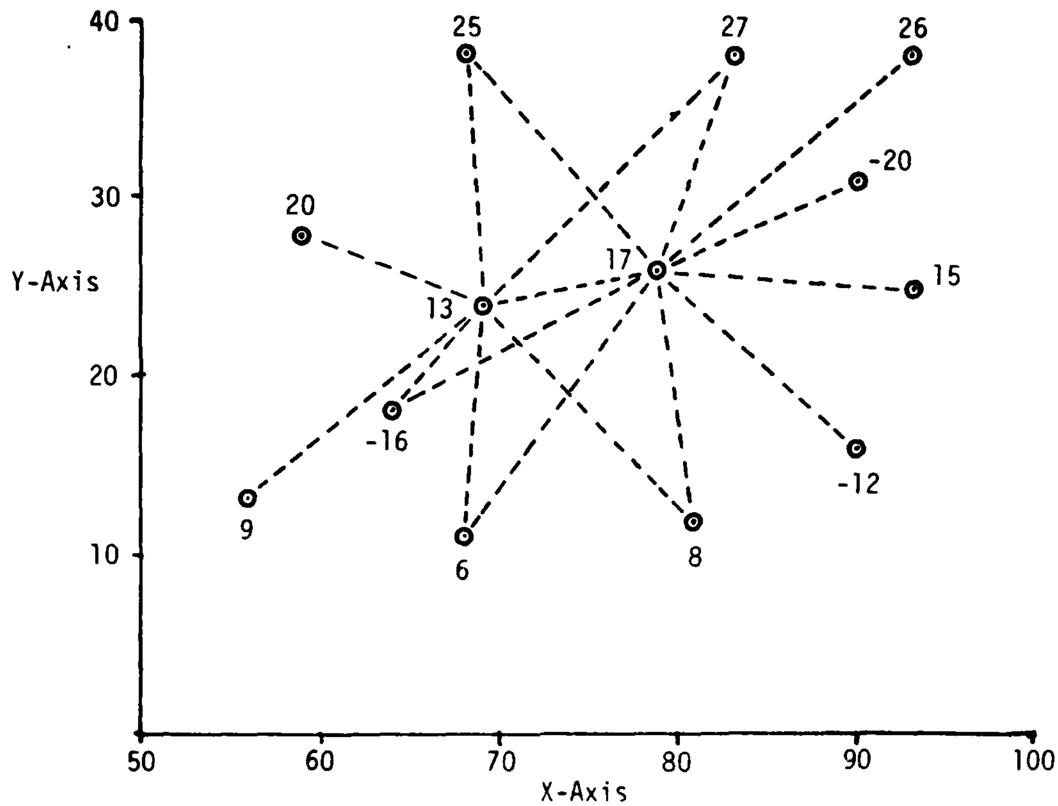

Figure 4.4 Node Linkage

Table 4.2 Node Links

Node 13 (113, 23, 300)					
No.	(X,Y,Z)	Distance	No.	(X,Y,Z)	Distance
6	(100, 10, 300)	13.038	20	(42, 27, 290)	10.770
8	(8, 10, 300)	16.971	25	(68, 8, 280)	14.036
9	(41, 12, 300)	17.029	27	(83, 38, 280)	19.799
17	(93, 25, 290)	10.198	-16	(64, 18, 290)	7.810
Node 17 (93, 26, 290)					
No.	(X,Y,Z)	Distance	No.	(X,Y,Z)	Distance
6	(100, 10, 300)	18.601	26	(93, 38, 280)	18.439
8	(81, 21, 290)	14.142	27	(83, 38, 280)	12.649
13	(113, 23, 300)	10.198	-12	(70, 16, 300)	14.866
15	(69, 24, 280)	14.036	-16	(64, 18, 290)	17.000
25	(68, 38, 280)	16.279	-20	(90, 31, 290)	12.083

Z_{min} = the minimum elevation of the neighborhood nodes,

ZR = the range between the maximum and minimum elevation in the neighborhood.

$0 \le ZP_j \le 1$

To account for distance from the central node, the penalty is associated with traveling short distances rather than long distances. The idea is to travel as far as possible in the neighborhood to reach a low, least exposed node. Thus the distance factor is given by:

$$DP_j = \left(1 - \frac{D_j - D_{min}}{DR}\right)$$

where DP_j = the penalty for a short distance between the central and neighborhood node,

D_j = the distance to the neighborhood node j,

D_{min} = the minimum distance,

DR = the range between the maximum and minimum distance in the neighborhood.

$0 \le DP_j \le 1$

Adding these two factors to the exposure value results in the following function.

$$\underset{j}{\underset{min}{EP(ij)}} = NS \cdot \left[\frac{R_{max} - \dfrac{\sum_{S=1}^{NS} R_{Sj}}{NS}}{R_{max}}\right] + \left(\frac{Z_j - Z_{min}}{ZR}\right) + \left(1 - \frac{D_j - D_{min}}{DR}\right).$$

The linkage (ij) is from node i to node j for which j is the minimum value within the neighbhorhood. Since each point and neighborhood is considered independently of any previous neighborhoods, this method is a dynamic programming approach to solving this problem.

The route objective is to provide a path to the terminal position. Therefore, some weighting should be given to those nodes which lie in the general direction of travel. To implement this idea, the vector-heading from the current position to the terminal node is found. The nodes which lie within 90° of either side of this heading have a weight of 1. Those nodes greater than 90° are located behind the current position and have a weight of 2. The exposure penalty of a neighborhood node is multiplied by this weight to give preference to those nodes which are ahead of the current position. If a position behind the current one has a very low exposure penalty it can still be selected, but the route procedure will reorient to the terminal node and will favor the destination direction.

When the route model has reached a position within 1 km of the terminal node the weighting scheme is modified to be more selective. The angle of preference is reduced to 45° of the route heading and pertains to those nodes lying inside the 1 km range. The weighting schemes for the selection process are given in Figures 4.5 and 4.6.

In developing the model, it was found that these weighting schemes lack one vital criterion - radar avoidance. The first two weightings provide the model with decision logic which improves the performance considerably; however, if the minimum exposure point was located on the other side of a sensor, then the logic would still choose this same point even though the route would then be directly over the sensor. After some testing of the model, a radar avoidance scheme was added to the weighting preference.

Air defense radars usually will have an acquisition range greater than the engagement range of the weapon system (guns or missiles). An

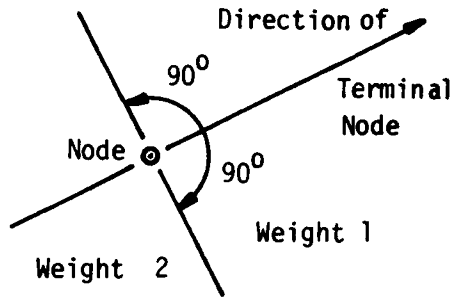

Figure 4.5 Weighting of Heading

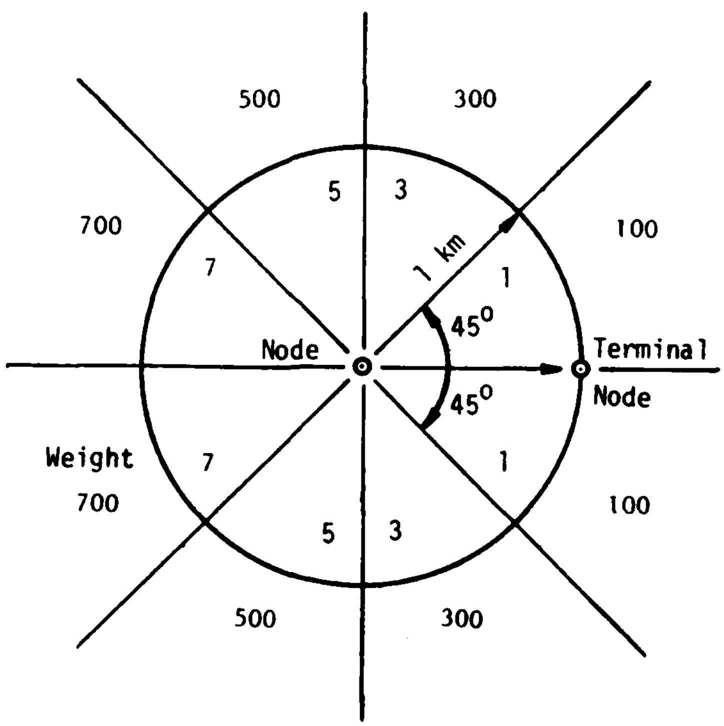

Figure 4.6 Weighting of Terminal Node

engagement boundary around the air defense site is assumed to be the weapon's kill radius. A vector from the current position to the sensor is calculated to give the azimuth and range to the sensor. A cone is used to form a high rejection area for nodes. The current position is the apex of the cone and the base is twice the kill radius, with the sensor at the base midpoint. A neighborhood node lying in this cone and ahead of the kill zone has a weight of 2. If it lies beyond this boundary the weight is 10. A node point which would cause the route to overfly or pass too close to the air defense site is thus avoided.

Figure 4.7 shows the relationship between the current node and the sensors, the terminal node and the new node. The angles shown in the figure are utilized in calculating the weighting values. Integer arithmetic allows a uniform weight to be assigned within any one area. The equations for calculating these weightings follows.

Angle of new node j from destination heading is:

$$ANT = \begin{cases} AN_j - AH & , -180° \leq ANT \leq 180° \\ AN_j - AH + 360°, & ANT < -180° \\ 360° + AH - AN_j, & ANT > 180° \end{cases}$$

Direction Weight is:

$$W_j = |ANT|/90° + 1$$

Terminal Weight is:

$$RW_j = \begin{cases} 2\,|ANT|/45° + 1 & , < 1 \text{ km} \\ (2\,|ANT|/45° + 1)\,100 & , > 1 \text{ km} \end{cases}$$

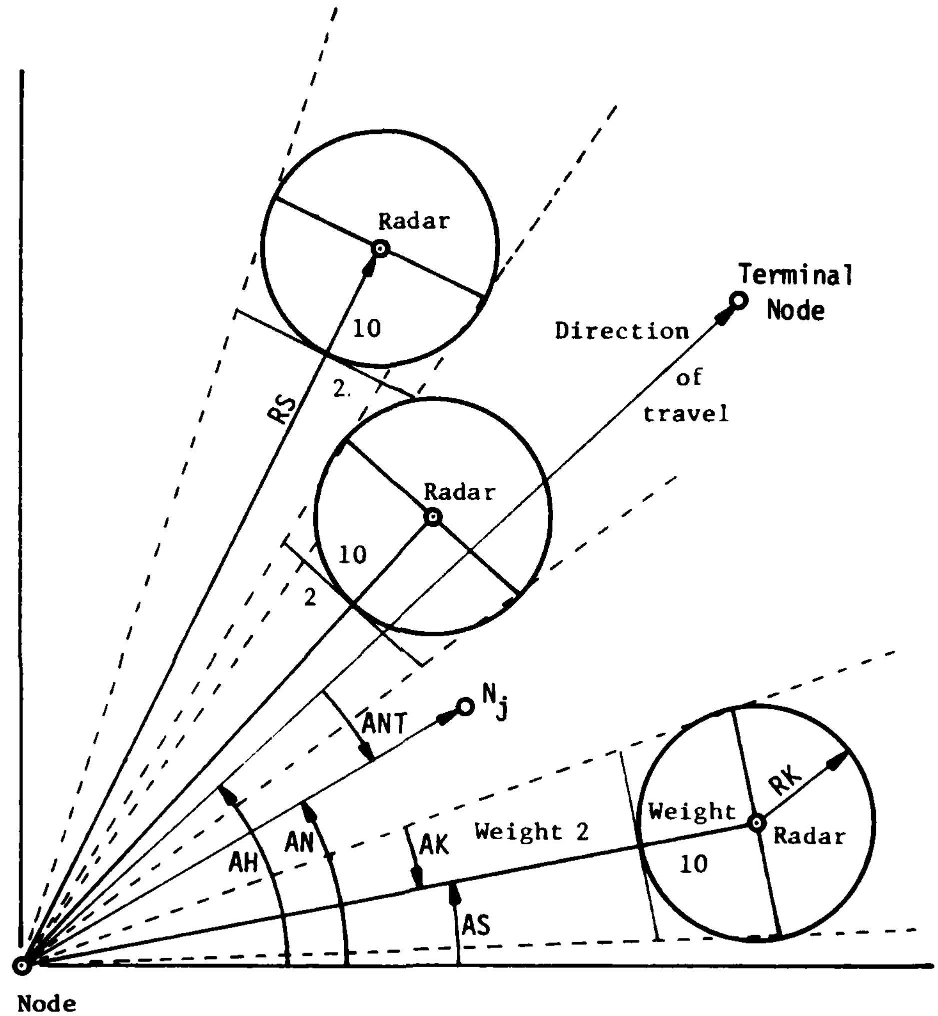

Figure 4.7 Radar Avoidance Weighting

Radar Avoidance Weight is:

$$AW_j = \begin{cases} 0\ , & AS - AN_j > AK \\ 2\ , & RN_j > RS - RK,\ AS - AN_j < AK \\ 10\ , & RN_j < RS - RK,\ AS - AN_j < AK \end{cases}$$

Where the variables in the equations and Figure 4.7 are:

AN_j = the angle from the x-axis to the new node j,

AH = the angle from the x-axis to the terminal node,

ANT = the angle between the new node and the terminal node,

AS = the angle to the sensor from the x-axis,

AK = the angle to each side of the sensor heading which would be within the kill radius,

RS = the range to the sensor from the current route node,

RK = the kill radius of the weapon system,

RN_j = the distance to the new node j,

The final exposure penalty for a node is defined by:

$$N_k = \min_j \quad (W_j + RW_j + AW_j) \cdot EP\ (ij)$$

Where N_k = the next node selected for the route,

W_j = the weight of node j based on its angle heading,

RW_j = the weight of node j based on its range to terminal node,

AW_j = the weight of node j based on whether or not it lies in the radar avoidance cone.

4.5 Route Refinement

A review of the resulting routes as developed by the model indicates a need for route refinement; therefore, it is necessary for the route selection logic to evaluate whether or not route nodes are

adjacent to each other. In an attempt to avoid air defense sites, the route may double back on itself. Thus, the route must be refined by determining if each node j ahead of the current position i is the closest one. If, for example, the ninth route node ahead of the current one is the closest position, then that node becomes the next node to link with node i. Node i is linked to node j by the following relation.

$$L(ij) = \min_{j} \left[(x_j - x_i)^2 + (y_j - y_i)^2\right]^{\frac{1}{2}}$$

$$j = i + 1, \ldots\ldots, n$$

where $L(ij)$ = the link between i and j,

(x_i, y_i) = the current node position,

(x_j, y_j) = the next node position.

With this refinement to the model route logic, a shorter more direct route to the destination can be found. With the model development complete, an example will be given in the next chapter.

CHAPTER V

ROUTE SELECTION EXAMPLE

5.1 Introduction

The model is now utilized in selecting a route. The example described in this chapter is a portion of a route found by the model. Additional route problems that were solved by the model are contained in Appendix A. The general computer outline of the model and each subroutine is given in Appendix B. In addition the model software is commented throughout for ease in understanding the logic.

The area of analysis is 10 by 10 km. This size area is large enough to exercise the model yet small enough to run in 30 CPU seconds (6.5 seconds compile, 23.04 execution). The actual terrain is rolling hills with an elevation range from 270 to 400 meters. Within this area, 3 sensors are located to provide radar coverage.

Two positions were arbitrarily selected on opposite sides of the area as an initial and terminal node. These two positions are situated such that the three sensors are between these points. Any route found will have to consider node positions that lie near the sensors since they act as a barrier to be crossed.

5.2 Elevation Nodes

The initial part of the model provides the clustering of terrain data into high and low elevation groups. Within each group a center is found that becomes a node point for selection. The example clustering results were 106 low elevation nodes and 94 high elevation nodes.

Within the low elevation group, the initial and terminal nodes are inserted so that when the nodes are ordered by rows they will be in sequence. The first node is also the initial node. The terminal node is number 86. All high nodes are indicated by a minus sign.

5.3 Line of Sight Calculations

The amount of calculation required in identifying the nodes is minimal and consists mostly of comparisons and list searching. The first portion requiring any degree of computation is the LOS calculation in subroutine RADIAL.

For these calculations low elevation node 10 and high elevation node -11 were selected as examples for determining LOS. Two sensors will be used, as the calculations for more combinations are the same. The coordinates of the two nodes and sensors are given in Table 5.1.

Table 5.1 Node-Sensor Coordinates

Node (N_i)	(X, Y, Z)	Sensor (R)	(X, Y, Z)
10	(29, 14, 310)	1	(68, 70, 300)
-11	(12, 16, 330)	2	(47, 99, 310)

The first step performed by the model is to determine if the node or sensor is the western most point. Comparing X values in Table 5.1 indicates that both nodes are to the West of sensor 1. Node 10 will be analyzed first.

Table 5.2 gives the initial values for the variables used in this example. The horizontal scale is one unit equals 70 meters and the vertical values are in meters.

Table 5.2 Parameter Values

Map Sheet	2
EAST	30
WEST	16
SOUTH	1
NORTH	150
Earth Curvature (RE) (radar 4/3)	8490200.0 meters
Vehicle Height (V) (Aircraft)	10.0 meters
Sensor Height (S)	3.0 meters
GRID	70.0 meters

The first value needed is the horizontal distance between the node and the sensor.

$$d = [(x_2 - x_1)^2 + (y_2 - y_1)^2]^{\frac{1}{2}}$$

$$d = [(68 - 29)^2 + (70 - 14)^2]^{\frac{1}{2}}$$

$$d = 68.242$$

The azimuth angle cosine and sine are:

$$\cos\alpha = (y_2 - y_1)/d$$

$$\cos\alpha = (70 - 14)/68.242$$

$$= 0.821$$

$$\sin\alpha = (x_2 - x_1)/d$$

$$\sin\alpha = (68 - 29)/68.242$$

$$= 0.571$$

The tangent between these two points will determine whether the eastern point lies above or below the horizontal as measured from the western point. When calculating the tangent, the height of the vehicle and sensor are added to the appropriate point. In addition, the earth curvature for the radar beam atmospheric refraction is accounted for by the following relation [16].

$$Ref = 0.5\ (d)(d)/(RE/GRID)$$

$$Ref = 0.5\ (68.242)(68.242)/(8490200.0/70)$$

$$= 2328.5/121288.57$$

$$= 0.0192$$

The tangent is:

$$\tan\beta = ((Z_R + S) - (Z_{N_i} + V) - REF)/(d)(GRID)$$

$$\tan\beta = (303 - 320 - 0.0192)/(68.242)(70)$$

$$= -0.0036$$

The absolute value of $\sin\alpha$ is compared to the sine of 45°. Since $0.571 < \sin 45°$, then the direction is either north or south. The cosine is a positive 0.821 which indicates a north heading. When the cosine is negative, a south heading is indicated. The y position is found for the north or south direction by incrementing y by one plus any west boundary offset. In this example the Left Comp y is zero. The integer value of y is used for the data base row index and is found by integer arithmetic.

$$ROW = y + \Delta y$$

$$= 14 + 1 = 15$$

$$ARRAY = (ROW - 1)/15 + 1$$

$$= (15 - 1)/15 + 1 = 1.93 = 1$$

$$ROW = ROW - (ARRAY - 1)(15)$$

$$= 15 - (1 - 1)(15) = 15$$

The column position can be found by the following.

$$COL = (\Delta y/\cos\alpha)\sin\alpha + x - WEST + 1$$

$$= (1/0.821)\ (0.571) + 29.0 - 16 + 1$$

$$= 14.70 = 14$$

The position of the first point to be extracted from the data base is located at (ROW, COL, ARRAY) = (15, 14, 1) of the second map sheet. Now that the elevation of 308 has been found at this point a tangent is calculated to determine if this new point masks node 10 from sensor 1. The distance to the new point, d', is given by:

$$d' = \Delta y/\cos$$
$$= 1/0.821 = 1.22$$
$$Ref' = 0.5\ (1.22)(1.22)/(8490200.0/70)$$
$$= 0.5\ (1.22)(1.22)/121288.57$$
$$= 0.000006$$

Tangent α for the new point is calculated by:

$$\text{Tan}\ \alpha = (Z_n - (Z_i + V) - Ref')/(d')(GRID)$$

where Z_n = the elevation of the new point.

$$\text{Tan}\ \alpha = (308 - 320 - 0.000006)/(1.22)(70)$$
$$= -0.14$$

Since tan α < tan β, this new point does not mask the node (-0.14<-.0036). The value of y is incremented to find the next grid point to be extracted from the data base.

$$y = 2$$
$$ROW = 14 + 2 = 16$$
$$ARRAY = (16 - 1)/15 + 1 = 2$$
$$ROW = 16 - (2 - 1)\ (15) = 1$$
$$COL = (2/0.821)\ \ (0.571) + 29.0 - 16 + 1$$
$$= 15.39 = 15$$

The second point from the data base is located in position (1, 15, 2) (Z = 304). Since the column is equal to 15, the eastern edge of the map sheet has been reached. In this case this second point does not mask the node, but any further calculations have to wait until the third map sheet is read into core storage.

The second node, number -11, is located on map sheet 1. Since this example began on map sheet 2, then the procedure for starting on the second map sheet, where the first map sheet processing stopped, will be shown. The basic calculations of sine, cosine, etc. are similar and are given below:

$$d = [(68 - 12)^2 + (70 - 16)^2]^{\frac{1}{2}}$$

$$= 77.795$$

$$\cos\alpha = (70 - 16)/77.795$$

$$= 0.694$$

$$\sin\alpha = (68 - 12)/77.795$$

$$= 0.720$$

$$\text{Ref} = 0.5 \quad (77.795)(77.795)/(121288.57)$$

$$= 0.0249$$

$$\tan\alpha = (303 - 340 - 0.0249)/(77.795)\ (70)$$

$$= -0.0068$$

In this case, **$\sin\alpha > \sin 45°$**; thus the direction is east. For a easterly vector the value of x is incremented by one to find the next position, but the value of y is calculated. Since x < WEST, x and COL are set to 1. The row index of y is calculated by

$$\text{ROW} = (\Delta x/\sin\alpha\ )\cos\alpha + y$$

$$= ((16 - 12 + 1)/\ 0.720)\ 0.694 + 16$$

$$= 20.82$$

$$\text{ARRAY} = (\text{ROW} - 1)/15 + 1$$

$$= (20.82 - 1)/15 + 1 = 2$$

$$\text{ROW} = \text{ROW} - (\text{ARRAY} - 1)\ (15)$$

$$= 20.82 - (1)(15) = 5$$

The first position in the second map sheet for node -11 is (5, 1, 2). The tangent of this new point is calculated the same as shown for node 10. The tan α < tan β in this case; therefore, the next position on the vector is found and checked for LOS.

The result of these computations is the number of sensors which can see this node. Having obtained this count on each node-sensor combination the exposure value for the node can be computed. For node 10 the count is 3, since all sensors can see this node. The R_{max} value for the node-sensor combinations in this example was found to be 161.941. The sum of the distances to the three sensors is 252.589. The exposure value is:

$$EP = NS \cdot \left[\frac{R_{max} - \dfrac{\sum_{S=1}^{NS} R_{Sj}}{NS}}{R_{max}} \right]$$

$$= 3 \cdot \left[\frac{161.941 - \dfrac{252.589}{3}}{161.941} \right]$$

$$= 1.440$$

5.4 Route Selection

For the route selection method, the initial point and the next to last point along a route were chosen as examples. The initial point is

also node 1 (7, 3, 270) and the terminal point is node 86 (87, 124, 310). Starting at node 1, the route seeks the minimum exposure point in the neighborhood. The nodes surrounding node 1 are given in Table 5.3.

Table 5.3 Neighborhood Nodes

Node	(x, y, z)	Distance	Exposure Value
4	(3, 9, 300)	7.211	0.672
-6	(13, 4, 400)	6.083	1.122
-8	(17, 5, 400)	10.198	1.167
-11	(12, 16, 330)	13.928	1.310

The distance and height penalties are now added to the exposure value for these points. The height penalty is given as:

$$ZP_j = \frac{Z_j - Z_{min}}{ZR}$$

$$ZP_4 = \frac{300 - 300}{100} = 0.0$$

$$ZP_{-6} = \frac{400 - 300}{100} = 1.0$$

$$ZP_{-8} = \frac{400 - 300}{100} = 1.0$$

$$ZP_{-11} = \frac{330 - 300}{100} = 0.3$$

The distance penalty is:

$$DP_j = 1.0 - \left(\frac{D_j - D_{min}}{DR}\right)$$

$$DP_4 = 1.0 - \left(\frac{7.211 - 6.083}{7.845}\right)$$

$$= 1.0 - 0.144 = 0.856$$

$$DP_{-6} = 1.0 - \left(\frac{6.083 - 6.083}{7.845}\right)$$

$$= 1.0$$

$$DP_{-8} = 1.0 - \left(\frac{10.198 - 6.083}{7.845}\right)$$

$$= 1.0 - 0.525 = 0.475$$

$$DP_{-11} = 1.0 - \left(\frac{13.928 - 6.083}{7.845}\right)$$

$$= 1.0 - 1.0 = 0.0$$

The final penalties associated with these nodes are:

Node	4	1.528
Node	-6	3.122
Node	-8	2.642
Node	-11	1.610

The direction weighting of these penalty values are determined by computing the azimuth of the terminal and neighborhood nodes. Table 5.4 gives the azimuth angle to the nodes, their weight and their final penalty value.

Table 5.4 Weighted Penalty Value

From	To	Angle x-axis	Angle from Heading	Weight	Penalty
1	86	56°	0°	-	-
1	4	123°	67°	1	1.528
1	-6	9°	-47°	1	3.122
1	-8	11°	-45°	1	2.642
1	-11	68°	12°	2	3.220

To compute the Table 5.4 entries for node 4 the following values are found using integer arithmetic.

$$\begin{aligned}
\text{x-axis } AN_4 &= \text{ARCTAN } (Y/X) \\
&= \text{ARCTAN } ((9-3)/(3-7)) \\
&= -56.31^\circ
\end{aligned}$$

Since the angle is negative, it is subtracted from 180°.

$$\begin{aligned}
AN_4 &= 180^\circ - 56.31^\circ = 123.69^\circ = 123^\circ \\
ANT &= 123^\circ - 56^\circ = 67^\circ \\
\text{Weight } W_j &= ANT / 90^\circ + 1 \\
&= 67^\circ/90^\circ + 1 \\
&= 0 + 1 = 1 \\
\text{Penalty } EP_{ij} &= (W_j)(EP_j) \\
&= (1)(1.528) = 1.528
\end{aligned}$$

Node -11 is the only one in Table 5.4 that utilized the radar avoidance weighting. Sensor 2 is almost collinear with nodes 1 and -11. For this example, the weapon system kill radius is 1.5 km or 21.43 in units of 70 meters. The calculations below would be made for all sensors and all nodes in the neighborhood, however, only node -11 is affected in this case.

Angle to sensor 2 is given by:

$$\begin{aligned}
\text{x-axis } AN_{-11} &= \text{ARCTAN } (Y/X) \\
&= \text{ARCTAN } ((99 - 3)/(47 - 7)) \\
&= 67.38^\circ = 67^\circ
\end{aligned}$$

Angle of 1/2 cone is given by:

$$RS = [(99 - 3)^2 + (47 - 7)^2]^{\frac{1}{2}}$$

$$= 104.00$$

$$AK = \text{ARCTAN } (21.43/104.00)$$

$$= 11.64°$$

Angle between sensor 2 and node -11 is given by:

$$AS - AP \text{ (from Table 5.4)}$$

$$-1° = 67° - 68°$$

$$-1° < 11.64°$$

Therefore, node -11 is in the cone of high rejection.

$$AW_j = 2, \text{ distance node } -11 < \text{sensor } 2$$

$$(13.9 < 104.00)$$

The next to last node along the route, number 78, utilizes the terminal weighting scheme. The values associated with node 78 are in Table 5.5. In this table the terminal node 86 has the smallest weighted exposure. The values in Table 5.5 are computed as shown previously except for the weight entry. The weight value for nodes 71 and 72 are found below.

For node 71:

$$RW_j = 2 \text{ ANT}/45° + 1 \quad , \quad (13.153)(70) < 1 \text{ km}$$

$$= 2\ (-179/45) + 1$$

$$= 2\ (4) + 1 = 7$$

Table 5.5 Node 78

From	To	Distance	Exposure	Height Penalty	Distance Penalty	Angle X-axis	Heading	Weight	Penalty
78	71	13.153	2.438	0.0	0.423	-98°	-179°	7	2009
78	72	15.000	2.306	0.0	0.000	-53°	-134°	500	115500
78	79	11.180	2.234	0.0	0.874	10°	-71°	3	933
78	86	13.153	0.730	0.5	0.423	81°	0°	1	163
78	-75	10.630	1.576	1.0	1.000	138°	57°	3	1059

For node 72:

$$RW_j = (2\ \text{ANT}/45° + 1)\ 100 \quad , \quad (15.0)(70) > 1\ \text{km}$$

$$= (2\ (-134/45) + 1)\ 100$$

$$= (2\ (2) + 1)\ 100 = 500$$

5.5 Route Refinement

To provide an example of route refinement consider the following situation given in Table 5.6.

Table 5.6 Linkage

From Node	(X, Y, Z)	To Node	(X, Y, Z)	Distance
31	(11, 45, 280)	30	(23, 43, 280)	12.166
30	—	28	(8, 40, 280)	15.297
28	—	35	(21, 50, 280)	16.401
35	—	34	(11, 49, 280)	10.050
34	—	45	(1, 64, 300)	18.028

The linkage between these points can be seen in Figure 5.1. From the figure, it is seen that node 34 is the closest node to node 31. The model determines this fact by comparing distances between nodes. The distance from node 31 to each of the nodes ahead of it is computed to the end of the route by the model; however, for this example, the process will stop at node 45. Table 5.7 gives the distance values for each of these nodes.

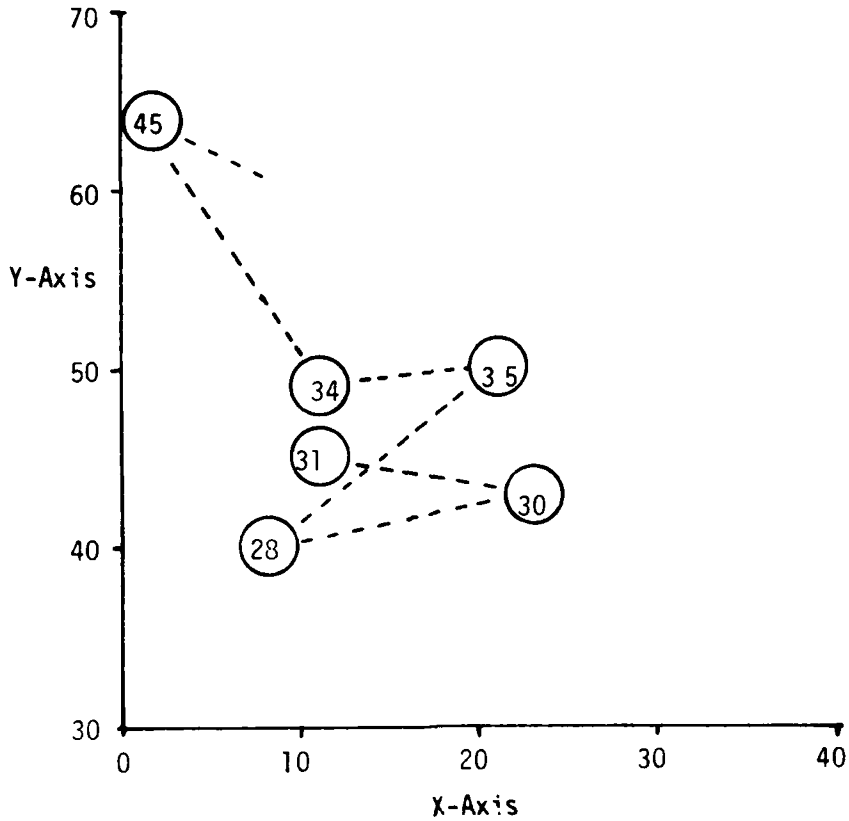

Figure 5.1. Linkage Example.

Table 5.7 Distance from Node 31

Node	Distance
30	12.166
28	5.831
35	11.180
34	4.000
45	21.471

The closest node to node 31 is node 34. In the refinement procedure, node 31 would be linked to node 34. Nodes 30, 28 and 35 would be eliminated from the route. The next node in the sequence, node 34, would now be compared with all nodes ahead of it for the closest node. The model continues to evaluate each new node on the route until the destination is reached. The results of this procedure become the refined route.

CHAPTER VI

MODEL RESULTS

6.1 Introduction

To evaluate the effect of sensor location on the route selection, two sets of sensor deployments were chosen along with two sets of beginning and end points. Since the test area was predominantly level terrain, a second small area was chosen of moderately rough terrain.

The results of the two small 10 by 10 km terrain areas are presented first, followed by the large 35 by 35 km area. To run the large terrain required increasing the dimensions of several primary arrays. The computer processing time for the large area increased by a factor of 10.

A plot of the route has proven to be the best analysis tool in evaluating the resulting routes. The tables provide the quantitative results; however, the route figures provide a visual comparison between routes that is discernible.

6.2 Small Area Analysis

The performance of this model was judged by varying sensor and route end points to provide different routes. Tables 6.1 and 6.2 provide the location of sensors and route end points utilized in the two small terrain areas. Each set of sensors was deployed against each route, resulting in four cases for each area as shown in Table 6.3.

Table 6.1 Sensor Locations

Area 1			
Set 1		Set 2	
Sensor	(X,Y,Z)	Sensor	(X,Y,Z)
1	(68, 70, 300)	1	(115, 116, 330)
2	(36, 119, 350)	2	(90, 84, 340)
3	(47, 99, 310)	3	(103, 45, 320)
Area 2			
Set 1		Set 2	
Sensor	(X,Y,Z)	Sensor	(X,Y,Z)
1	(28, 114, 330)	1	(78, 57, 350)
2	(61, 90, 380)	2	(85, 42, 340)
3	(78, 71, 350)	3	(100, 17, 320)

Table 6.2 Initial and Final Route Points

Area 1				
Route	Node	From (X,Y,Z)	Node	To (X,Y,Z)
1	1	(7, 3, 270)	86	(87, 124, 310)
2	31	(11, 45, 280)	96	(135, 135, 360)
Area 2				
Route	Node	From (X,Y,Z)	Node	To (X,Y,Z)
1	3	(26, 4, 350)	81	(118, 111, 310)
2	35	(11, 50, 300)	84	(128, 114, 320)

Table 6.3 Route Cases

Case	Area	Route	Sensor Set
1	1	1	1
2	1	2	1
3	1	1	2
4	1	2	2
5	2	1	1
6	2	2	1
7	2	1	2
8	2	2	2

The initial point and the destination point are placed in the low elevation array with their node number within that array given in Table 6.2. Except for the initial and destination nodes, the set of high and low elevation nodes for an area is determined solely on elevation. They remain constant for all scenarios. Table 6.4 indicates 106 low elevation nodes and Table 6.5 indicates 94 high elevation nodes. Tables 6.6 and 6.7 give the exposure values of these nodes for the first set of sensors. These values will change with each sensor deployment and the number of sensors. The first entry in Table 6.6 corresponds to the first entry in Table 6.4 with the other values corresponding in the order given. Likewise, Table 6.7 entries correspond to the entries in Table 6.5 in the same manner. The data contained in these four tables provide the basic information required for the route selection.

The results of the route selection process for the first case is given in Table 6.8. The node linkage is from node i to node j with the

Table 6.4. Low Elevation Node Points

X-COORDINATE	7	138	128	3	112	100	68	81	41	56
Y-COORDINATE	3	8	8	5	10	10	11	12	12	13
Z-COORDINATE	270	300	300	300	300	300	290	290	300	290
X-COORDINATE	29	128	113	6	69	141	93	79	25	42
Y-COORDINATE	14	22	23	24	24	25	25	26	27	27
Z-COORDINATE	310	300	300	300	280	300	290	280	300	290
X-COORDINATE	59	121	146	112	68	93	83	53	8	39
Y-COORDINATE	28	31	34	35	38	38	38	38	40	42
Z-COORDINATE	280	300	300	300	280	280	280	280	280	280
X-COORDINATE	23	37	55	11	21	68	83	93	112	145
Y-COORDINATE	43	47	49	45	50	51	52	54	56	59
Z-COORDINATE	280	280	280	280	280	280	280	280	300	300
X-COORDINATE	127	84	94	67	1	25	56	128	113	143
Y-COORDINATE	59	63	63	63	64	64	65	66	66	68
Z-COORDINATE	310	290	290	290	300	300	290	300	300	300
X-COORDINATE	36	94	144	134	8	30	42	68	53	83
Y-COORDINATE	68	76	76	76	77	77	81	83	83	83
Z-COORDINATE	300	300	300	310	340	310	300	300	300	300
X-COORDINATE	108	92	150	30	44	111	55	69	124	8
Y-COORDINATE	89	85	91	91	93	94	95	97	98	98
Z-COORDINATE	330	300	360	330	310	330	300	300	350	350
X-COORDINATE	63	94	150	106	45	56	73	85	56	106
Y-COORDINATE	98	99	105	105	106	106	107	111	113	114
Z-COORDINATE	300	300	360	330	330	320	300	300	300	310
X-COORDINATE	7	145	122	16	16	97	11	113	57	123
Y-COORDINATE	117	119	119	120	122	124	127	128	128	129
Z-COORDINATE	300	340	330	300	300	310	300	330	330	330
X-COORDINATE	86	91	147	75	32	23	14	25	83	38
Y-COORDINATE	129	129	132	135	135	135	137	141	143	144
Z-COORDINATE	300	300	330	310	310	300	300	300	300	300
X-COORDINATE	96	53	146	65	106	124				
Y-COORDINATE	145	146	146	147	149	150				
Z-COORDINATE	300	300	320	300	300	320				

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Table 6.5. High Elevation Node Points

X-COORDINATE	32	46	67	121	149	13	115	17	94	75
Y-COORDINATE	3	3	3	3	3	4	5	5	5	6
Z-COORDINATE	330	310	300	310	330	400	310	400	310	300
X-COORDINATE	12	90	31	47	18	64	147	100	127	90
Y-COORDINATE	16	16	17	18	18	18	20	24	30	31
Z-COORDINATE	330	300	310	330	330	290	310	300	320	290
X-COORDINATE	11	47	21	35	128	115	141	105	105	116
Y-COORDINATE	32	32	35	37	39	42	42	45	46	49
Z-COORDINATE	290	290	300	290	330	330	330	330	320	330
X-COORDINATE	140	129	38	27	68	48	82	10	83	51
Y-COORDINATE	53	54	56	57	55	59	59	60	70	70
Z-COORDINATE	330	330	300	300	290	300	290	310	300	300
X-COORDINATE	66	8	32	17	113	122	104	139	90	105
Y-COORDINATE	71	72	74	74	75	75	75	75	80	80
Z-COORDINATE	300	330	310	330	340	330	330	310	310	340
X-COORDINATE	115	8	33	17	135	47	142	135	22	104
Y-COORDINATE	83	87	88	89	50	90	90	97	99	99
Z-COORDINATE	350	350	330	350	370	310	390	400	350	330
X-COORDINATE	142	115	47	32	61	105	135	9	142	116
Y-COORDINATE	99	101	104	104	105	106	107	107	108	109
Z-COORDINATE	400	350	330	350	320	330	350	350	400	350
X-COORDINATE	25	35	65	49	77	135	140	77	27	67
Y-COORDINATE	113	115	116	116	118	122	124	127	127	128
Z-COORDINATE	350	350	330	340	320	350	350	320	350	330
X-COORDINATE	103	48	41	2	104	44	127	49	64	77
Y-COORDINATE	129	129	130	131	137	137	137	137	138	138
Z-COORDINATE	330	350	350	380	330	340	340	340	330	310
X-COORDINATE	3	140	115	17						
Y-COORDINATE	143	143	144	148						
Z-COORDINATE	380	330	330	340						

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Table 6.6. Exposure Values for Low Elevation Nodes

0.000	.697	.825	.672	1.039	1.160	1.381	1.339	1.405	1.440
1.382	.526	1.217	1.380	1.612	0.000	1.465	1.595	1.587	1.675
1.711	0.000	0.000	1.390	1.866	1.666	1.766	1.892	0.000	1.275
0.000	.762	1.400	0.000	0.000	2.095	1.984	1.283	1.624	.520
1.404	2.118	1.970	2.307	0.000	1.477	2.347	.629	1.688	.537
2.300	2.066	0.000	0.000	1.315	1.590	1.710	2.459	2.526	2.268
1.863	2.134	0.000	1.555	1.753	1.811	2.582	2.452	1.579	1.375
2.264	2.090	0.000	1.874	2.594	2.548	1.601	1.480	1.996	1.832
0.000	0.000	.950	0.000	0.000	.647	0.000	1.623	1.494	1.457
.619	.609	.310	0.000	0.000	0.000	0.000	0.000	0.000	0.000
.506	0.000	.301	0.000	.530	.424				

Table 6.7. Exposure Values for High Elevation Nodes

1.214	1.253	1.149	.836	.486	1.122	.932	1.167	1.129	1.265
1.310	1.345	1.454	1.526	1.390	1.520	0.000	1.380	.214	1.589
1.107	1.777	1.685	1.815	.625	1.433	1.034	1.610	1.622	1.494
1.142	1.332	2.135	2.060	2.233	2.234	2.055	.637	2.203	2.398
2.421	.629	2.317	.684	1.739	.665	1.894	0.000	2.149	1.697
1.731	1.352	2.455	1.445	1.385	2.574	1.259	1.384	1.513	1.925
1.256	1.732	2.607	1.598	2.509	1.687	1.366	.818	1.239	1.690
1.547	1.630	1.535	2.505	1.445	.827	.762	1.386	1.492	1.442
1.766	1.519	1.519	1.222	1.096	.878	1.329	.863	.791	0.000
1.144	.706	.947	.786						

Table 6.8. NODE LINKAGE FOR ROUTE

FROM	EASTING	NORTHING	TO	PENALTY	EASTING	NORTHING
1	490	7210	4	153	210	7630
4	210	7630	-8	263	1190	7350
-8	1190	7350	11	164	2030	7980
11	2030	7980	9	207	2870	7840
9	2870	7840	10	145	3920	7910
10	3920	7910	15	186	4830	8680
15	4830	8680	27	177	5810	9660
27	5810	9660	26	266	6510	9660
26	6510	9660	-29	278	7350	10220
-29	7350	10220	39	247	7840	10920
39	7840	10920	49	242	7910	11620
49	7910	11620	48	152	8960	11620
48	8960	11620	-48	58	9730	12250
-46	9730	12250	53	202	10080	12320
53	10080	12320	63	72	10500	13370
63	10500	13370	73	27	10500	14350
73	10500	14350	82	57	10430	15330
82	10430	15330	93	96	10290	16240
93	10290	16240	103	124	10220	17220
103	10220	17220	83	156	8540	15330
83	8540	15330	88	228	7910	15960
88	7910	15960	-85	234	7280	16590
-85	7280	16590	-90	44	5390	16660
-90	5390	16660	86	97	6090	15680

Table 6.9. Node Linkage

```
NODE NO.    1 TOTAL LINKS    4
X,Y,Z COORDINATE    7.    3.  270
LINKED TO          4      -6      -8     -11
EXPOSURE         152     311     263     160
WEIGHTED         153     312     264     322

NODE NO.    4 TOTAL LINKS    5
X,Y,Z COORDINATE    3.    9.  300
LINKED TO         14      -6     -11      -8     -15
EXPOSURE         172     311     257     262     168
WEIGHTED         346     312     516     263     338

NODE NO.   -8 TOTAL LINKS    6
X,Y,Z COORDINATE   17.    5.  400
LINKED TO         11      -6     -11     -15      -1     -13
EXPOSURE         163     311     197     198     166     145
WEIGHTED         164     624     198     398     167     292

NODE NO.   11 TOTAL LINKS    6
X,Y,Z COORDINATE   25.   14.  310
LINKED TO          9      19      20     -13      -1     -15
EXPOSURE         206     215     167     294     266     281
WEIGHTED         207     216     336     590     534     564

NODE NO.    9 TOTAL LINKS    5
X,Y,Z COORDINATE   41.   12.  300
LINKED TO         10     -14      -2     -13      -1
EXPOSURE         144     277     246     253     254
WEIGHTED         145     278     494     254     510

NODE NO.   10 TOTAL LINKS    7
X,Y,Z COORDINATE   56.   13.  290
LINKED TO          7      21      15      20     -16     -14      -2
EXPOSURE         244     214     187     199     284     308     276
WEIGHTED         245     430     188     200     285     309     554

NODE NO.   15 TOTAL LINKS    7
X,Y,Z COORDINATE   65.   24.  290
LINKED TO         18      21       7      25       8      27     -16
EXPOSURE         239     246     285     234     248     176     342
WEIGHTED         240     247     572     470     498     177     686

NODE NO.   27 TOTAL LINKS    7
X,Y,Z COORDINATE   83.   36.  280
LINKED TO         26      18      37      25      17      36     -20
EXPOSURE         265     231     257     235     272     209     349
WEIGHTED         266     464    2580     472     546    2100     700

NODE NO.   26 TOTAL LINKS    7
X,Y,Z COORDINATE   93.   35.  280
LINKED TO         17      37      18     -20     -28     -29     -19
EXPOSURE         216     209     159     278     301     277     202
WEIGHTED         434     420     320     558     302     278     406

NODE NO.  -29 TOTAL LINKS    7
X,Y,Z COORDINATE  105.   46.  320
LINKED TO         39      24      38     -29     -26     -30     -20
EXPOSURE         246     218     161     359     293     295     179
WEIGHTED         247     438     324     720     588     296     358

NODE NO.   39 TOTAL LINKS    5
X,Y,Z COORDINATE  112.   56.  300
LINKED TO         49      41     -30     -28     -26
EXPOSURE         241     172     346     289     253
WEIGHTED         242     346     694     580     508

NODE NO.   49 TOTAL LINKS    6
X,Y,Z COORDINATE  113.   66.  300
LINKED TO         48      41     -45     -46     -47     -50
EXPOSURE          78     171     371     187     310     287
WEIGHTED         158     349     372     188     622     266
```

Table 6.9. (cont'd.)

```
NODE NO.   46 TOTAL LINKS     8
X,Y,Z COORDINATE  126.   66.  300
LINKED TO         41      54      50     -46     -32     -48     -45     -31
EXPOSURE         264      81      77     204     255      57     273     187
WEIGHTED         530      52     156     205     520      58     546     376

NODE NO.  -49 TOTAL LINKS     4
X,Y,Z COORDINATE  139.   75.  310
LINKED TO         53      54      50     -55
EXPOSURE         190     114     125     237
WEIGHTED         252     230     252     238

NODE NO.   53 TOTAL LINKS     5
X,Y,Z COORDINATE  144.   76.  300
LINKED TO         50      54      63     -57     -55
EXPOSURE         153      68      71     253     215
WEIGHTED         302      69      72     254     216

NODE NO.   63 TOTAL LINKS     5
X,Y,Z COORDINATE  150.   91.  360
LINKED TO         73     -57     -61     -55     -58
EXPOSURE          26     299     283     176     235
WEIGHTED          27     630     284     354     472

NODE NO.   73 TOTAL LINKS     7
X,Y,Z COORDINATE  150.  105.  360
LINKED TO         82     -69     -61     -67     -58     -57     -55
EXPOSURE          56     322     312     266     270     241     187
WEIGHTED          57     323     313     534     542     242     188

NODE NO.   82 TOTAL LINKS     5
X,Y,Z COORDINATE  145.  115.  340
LINKED TO         93     -77     -69     -76     -67
EXPOSURE          95     214     288     161     221
WEIGHTED          96     215     289     162     444

NODE NO.   93 TOTAL LINKS     4
X,Y,Z COORDINATE  147.  132.  330
LINKED TO        103     -77     -92     -76
EXPOSURE          61     273     154     179
WEIGHTED         124     548     155     360

NODE NO.  103 TOTAL LINKS     6
X,Y,Z COORDINATE  146.  146.  320
LINKED TO         90      83     -92     -87     -77     -76
EXPOSURE         171      98     170     231     216     210
WEIGHTED         344     198     342     464     217     211

NODE NO.   83 TOTAL LINKS     5
X,Y,Z COORDINATE  122.  119.  330
LINKED TO         90      88     -70     -76     -67
EXPOSURE         245     227     280     172     234
WEIGHTED         246     228     281     345     470

NODE NO.   88 TOTAL LINKS     5
X,Y,Z COORDINATE  111.  126.  330
LINKED TO         90      80     -81     -85     -87
EXPOSURE         310     198     341     233     229
WEIGHTED         622     398     342     234     460

NODE NO.  -85 TOTAL LINKS    12
X,Y,Z COORDINATE  104.  137.  330
LINKED TO         91      90      88      83      79      78     -81     -87     -90     -78
LINKED TO        -70     -75
EXPOSURE         115     254     130     242     238     151     335     251      43     194
EXPOSURE         277     183
WEIGHTED         232     510     262     243     462     304     336     504      44     390
WEIGHTED         278     368

NODE NO.  -90 TOTAL LINKS     5
X,Y,Z COORDINATE   77.  138.  310
LINKED TO         91      66     -78     -89     -83
EXPOSURE         134      96     303     243     290
WEIGHTED         135      97     608     483     582
```

corresponding penalty associated with this pairing. The easting and northing values are the number of meters from the southwest corner of the area. This corner is the standard position for reference on a map. Knowing the southwest corner of the actual map area being analyzed, the nodes can be positioned on the map by finding the point X meters easting and Y meters northing from the southwest corner. Table 6.9 contains the neighborhood nodes for each node along the route. Three data items are provided: The nodes are listed on the third line, the unweighted exposure value pertaining to that node is listed on the fourth line, and the final weighted penalty for the node is given on the fifth line.

Figure 6.1 shows the position of the sensors and the resulting route for the first case. The route avoids the air defense sensors by traveling east before turning north. The destination point is approached from an easterly direction.

Figures 6.2 through 6.8 are the resulting routes for the cases listed in Table 6.3. In each Figure the location of the sensors are shown. The terrain in Figures 6.1 through 6.4 is flat to moderately hilly. There is a valley that proceeds from the southwest to the northeast through the center of this terrain. The rough terrain is located to the southeast and east. A large flat-top hill is located in the northwest.

The terrain in the second area is rougher (Case 5 through 8). There is a prominent ridge running from the southeast to the center of the area. There are valleys on each side of this ridgeline that join in the northwest. In Figures 6.5 and 6.7, the route selection was difficult with the sensors located in the northern and central areas. When the sensors were located on top of the ridge and to the south,

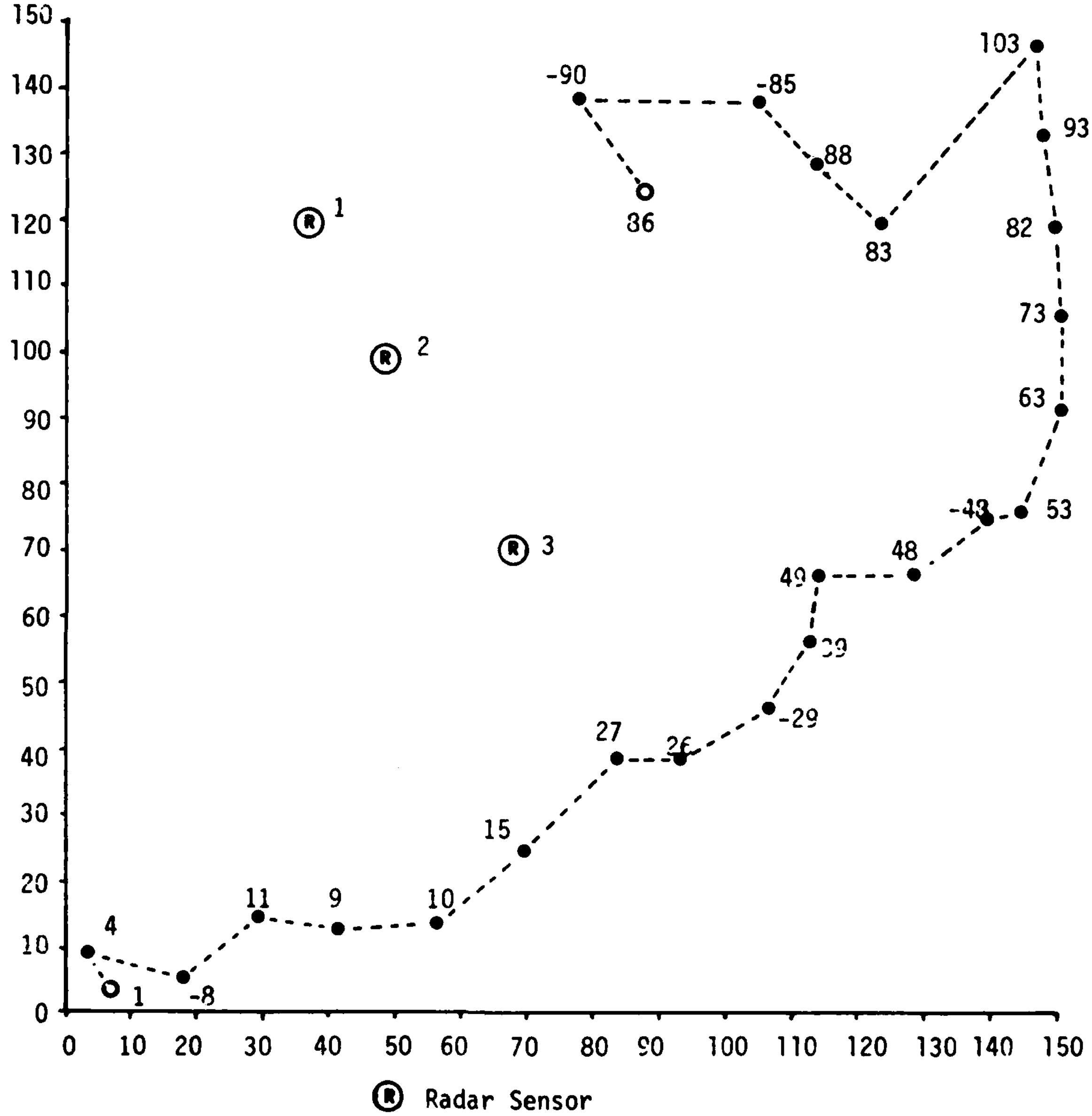

Figure 6.1. Case 1 - A1, R1, S1.

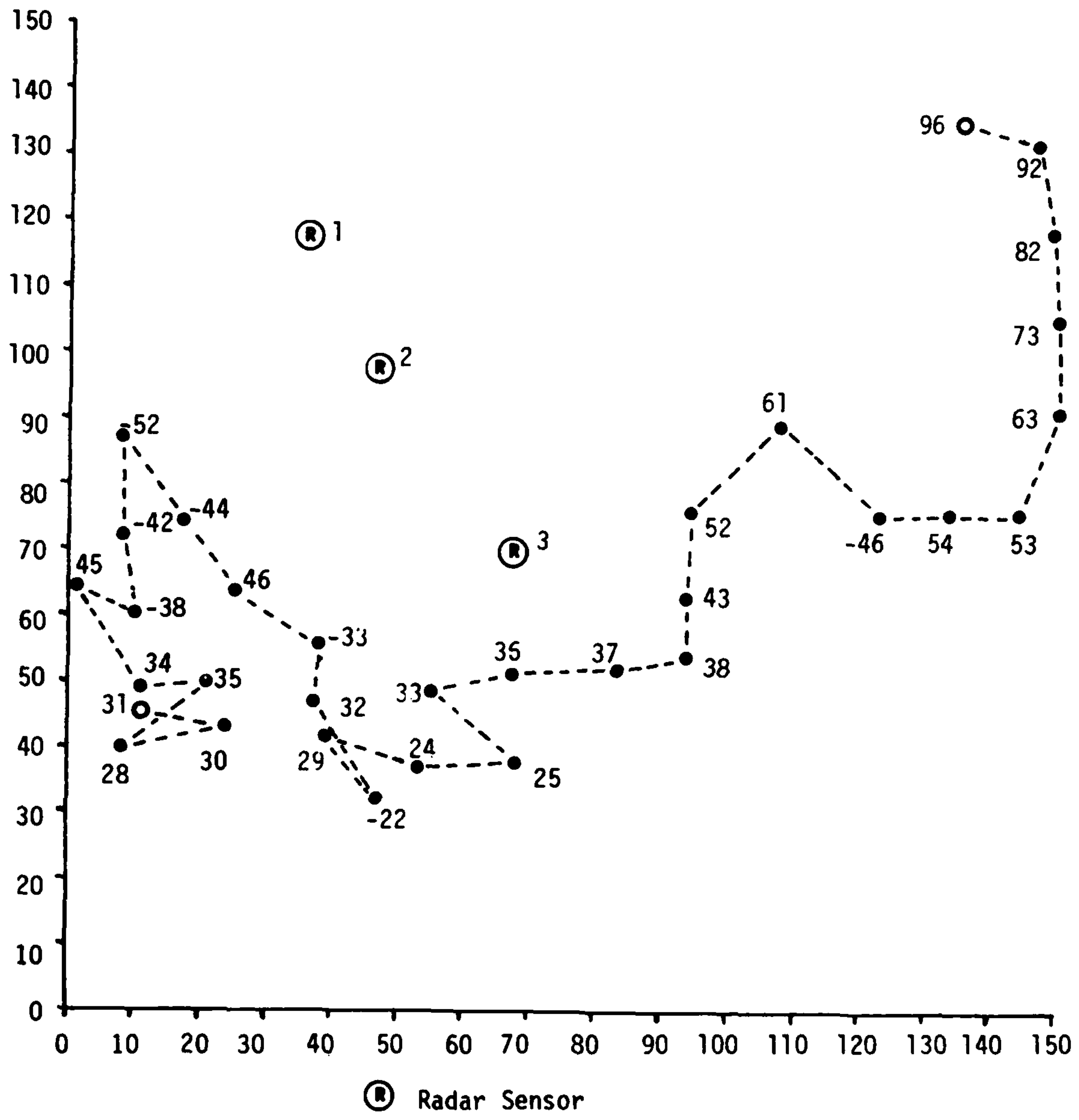

Figure 6.2. Case 2 - A1, R2, S1.

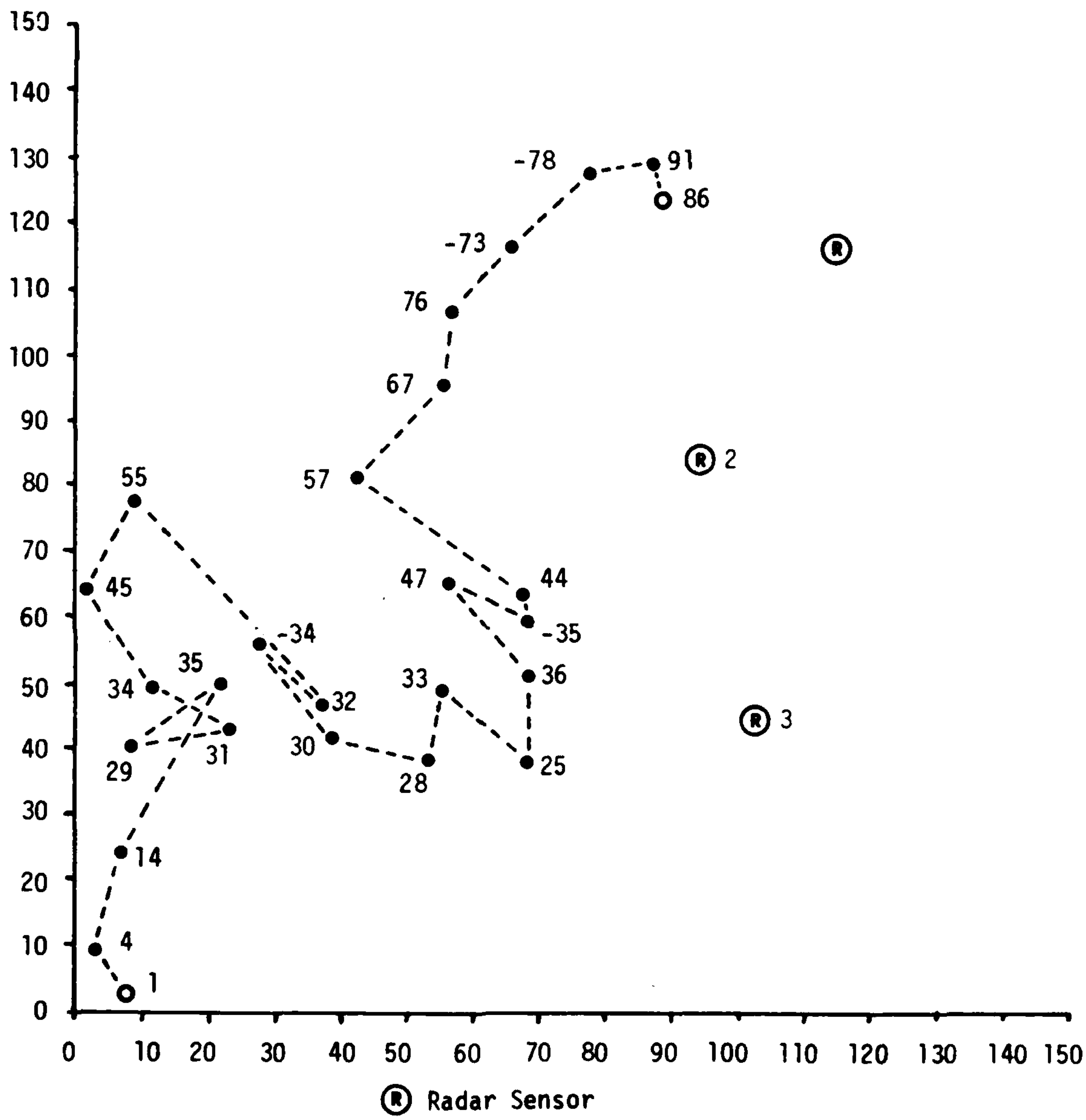

Figure 6.3. Case 3 - A1, R1, S2.

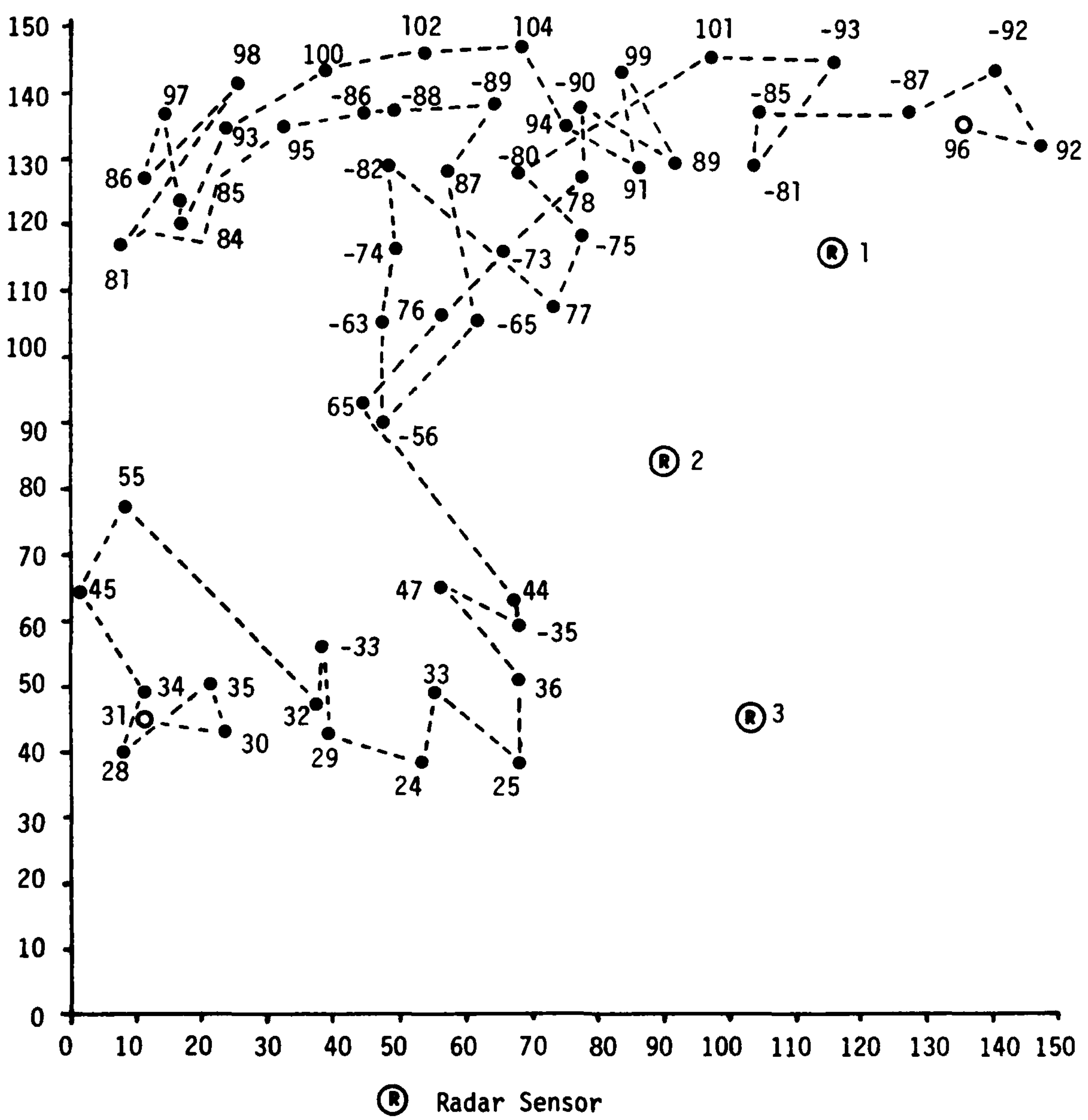

Figure 6.4. Case 4 - A1, R2, S2.

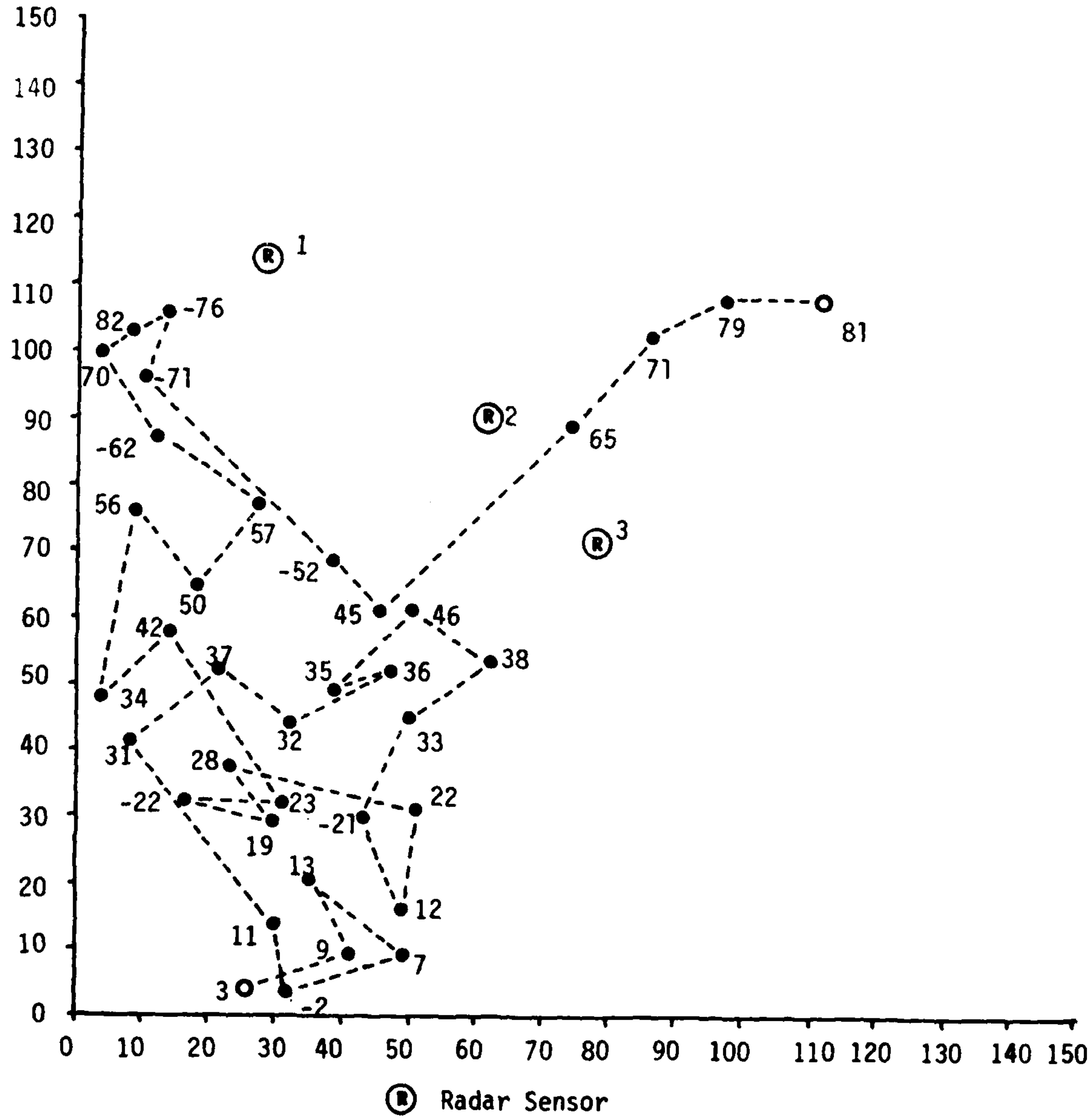

Figure 6.5. Case 5 - A2, R1, S1.

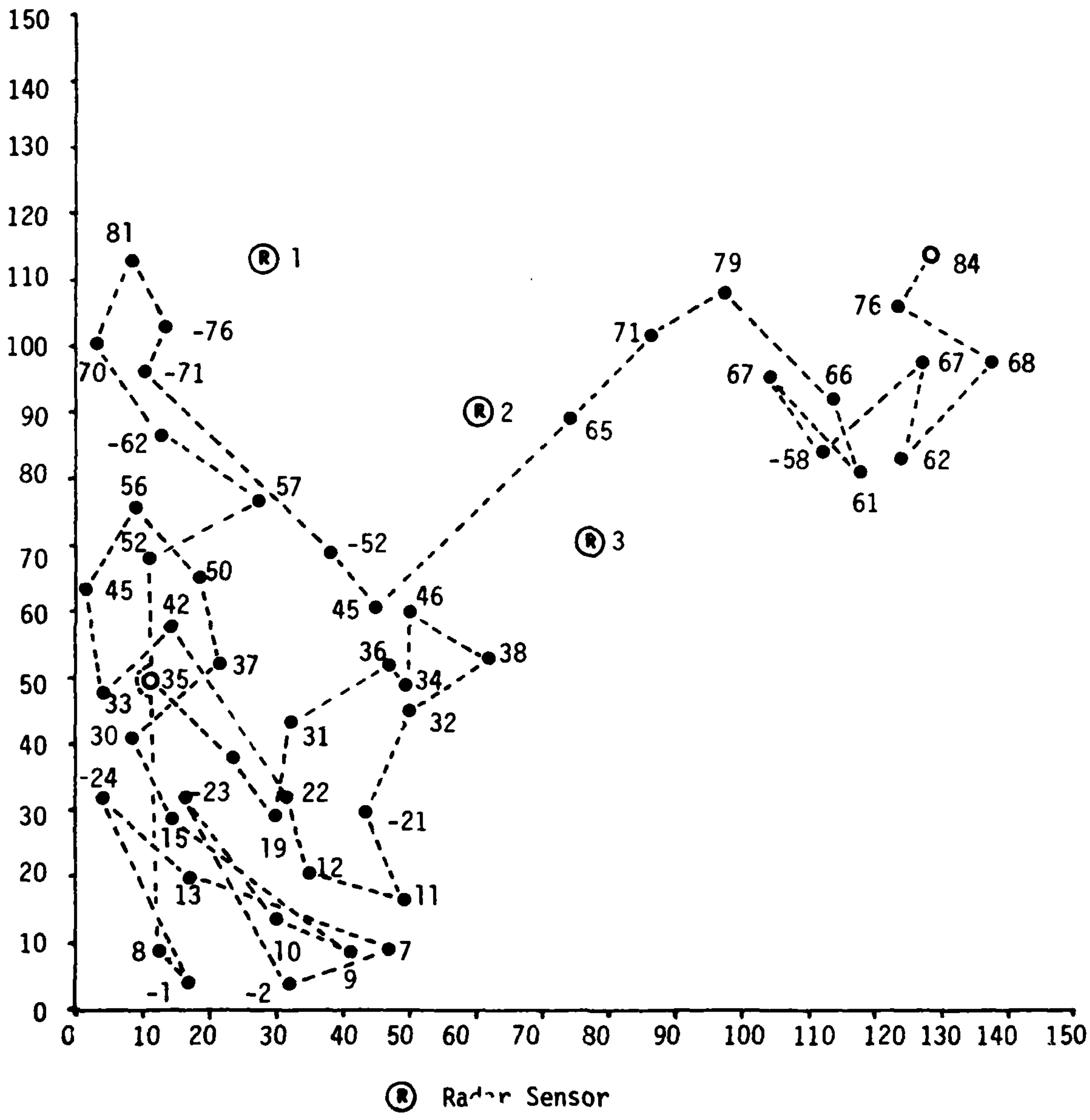

Figure 6.6. Case 6 - A2, R2, S1.

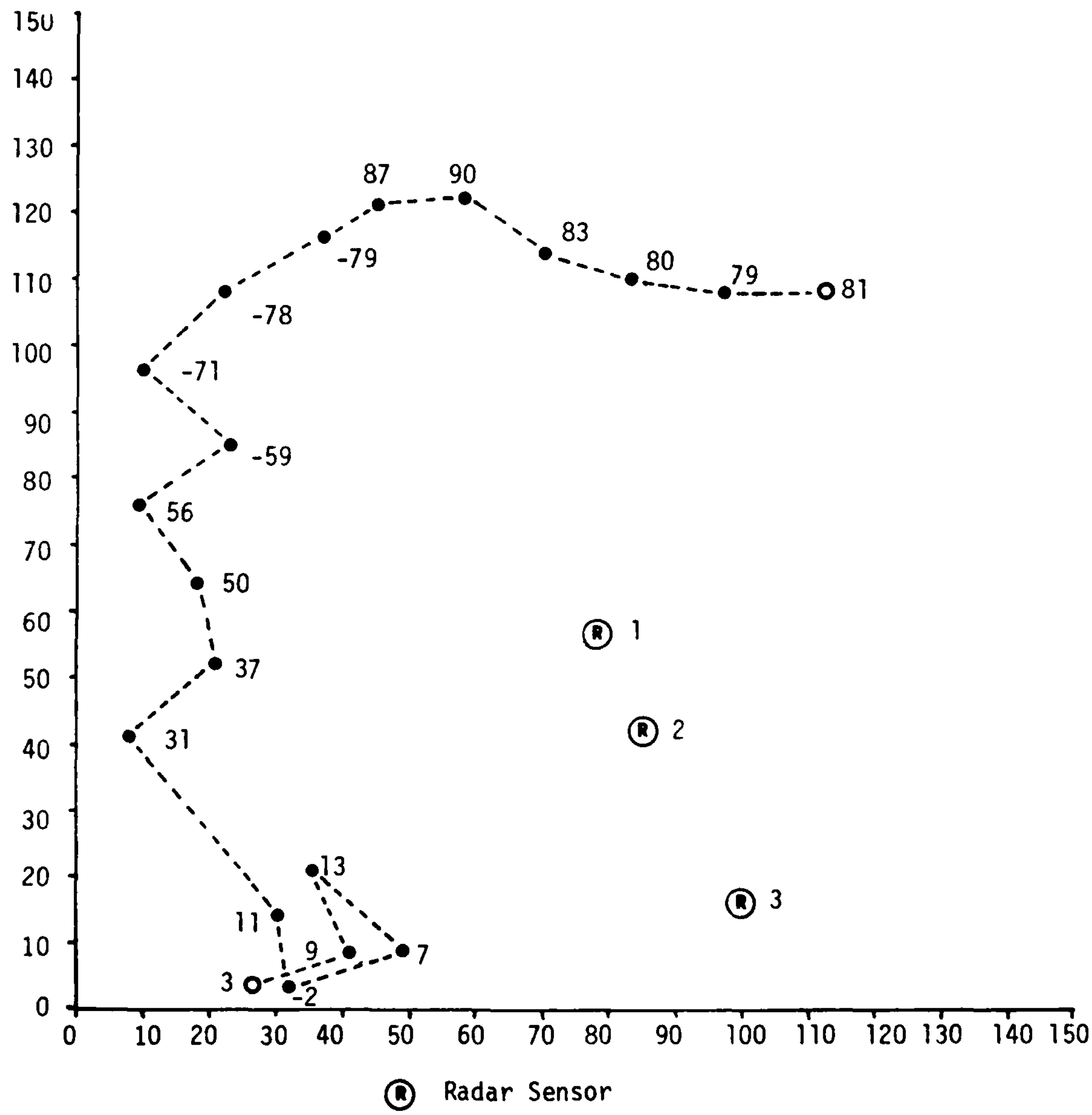

Figure 6.7. Case 7 - A2, R1, S2.

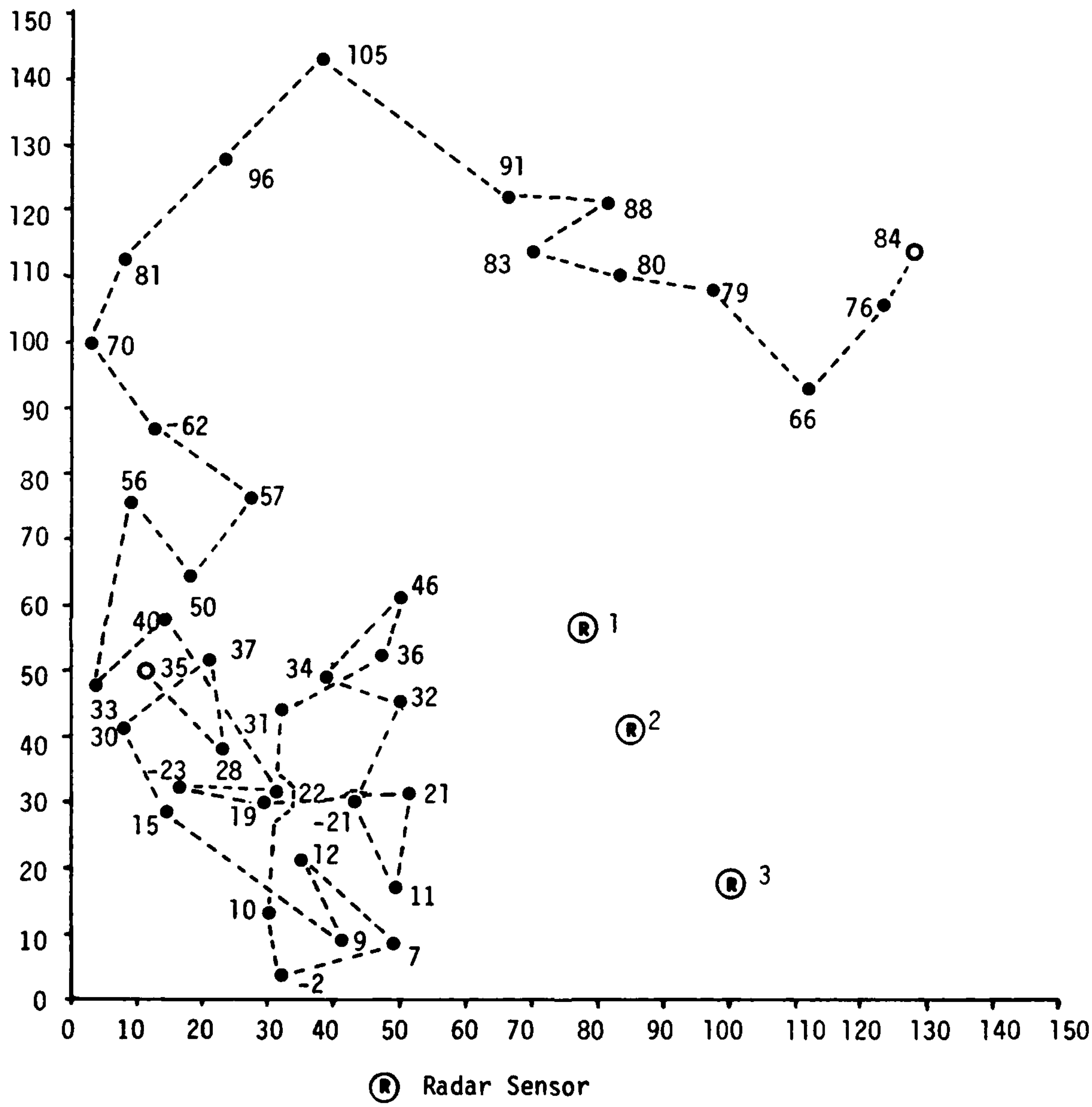

Figure 6.8. Case 8 - A2, R2, S2.

the routes selected follow the base of this ridge (Figures 6.6 and 6.8).

6.3. Refined Routes

These initial routes shown in Figures 6.1 through 6.8 were refined and the new routes are shown in those cases where improvement could be achieved. For case one, the refinement process accepted the initial results as final.

In the other cases improvement was achieved by the refinement process. The improvement in case two occurs at the beginning of the route (Figure 6.9). The route initially headed north and was not able to avoid the air defenses. The model reversed directions and utilized a southern route. The route refinement eliminates the first several nodes to achieve the improvement.

The radars are located in the east for cases three and four. The initial routes are to the north; however, the hilly region in the northwest caused the selection process to change directions and proceeds south. The refinement in case three smoothed the initial portion of the route (Figure 6.10). The destination point in case four is located beyond the line of radars; thus, causing the route selection to double back to avoid the air defenses. There is significant improvement when the route is refined (Figure 6.11).

In area two, the rougher terrain resulted in three of the four routes doubling back significantly. With the radars deployed on the high ground to cover the approach corridors, the route meanders considerably since the model searched for an acceptable low exposure route (Figures 6.5 and 6.6). The selection process finally reached node 45 from which the radars could be breached. Figures 6.12 and 6.13

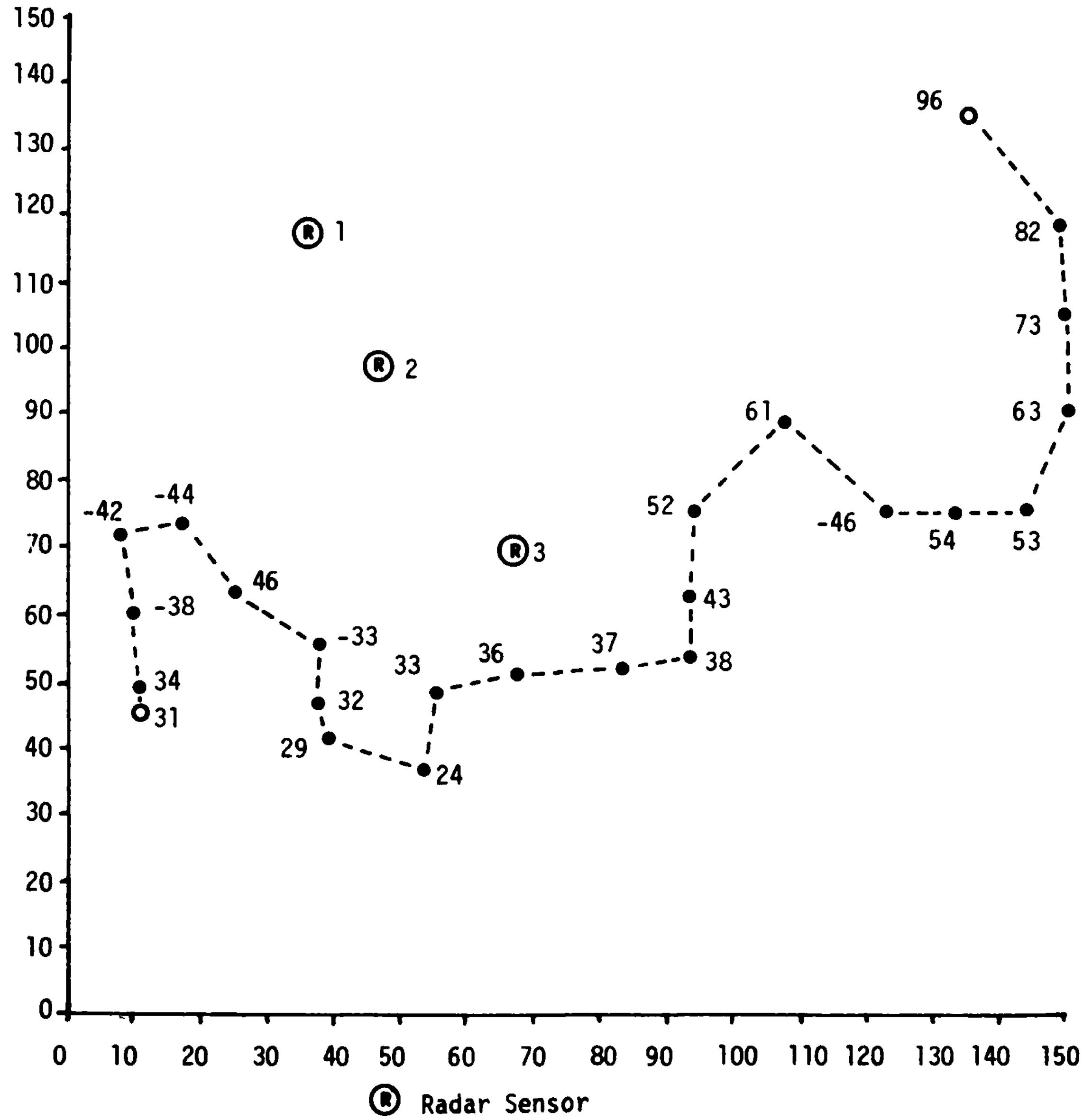

Figure 6.9. Case 2 - Refined Route.

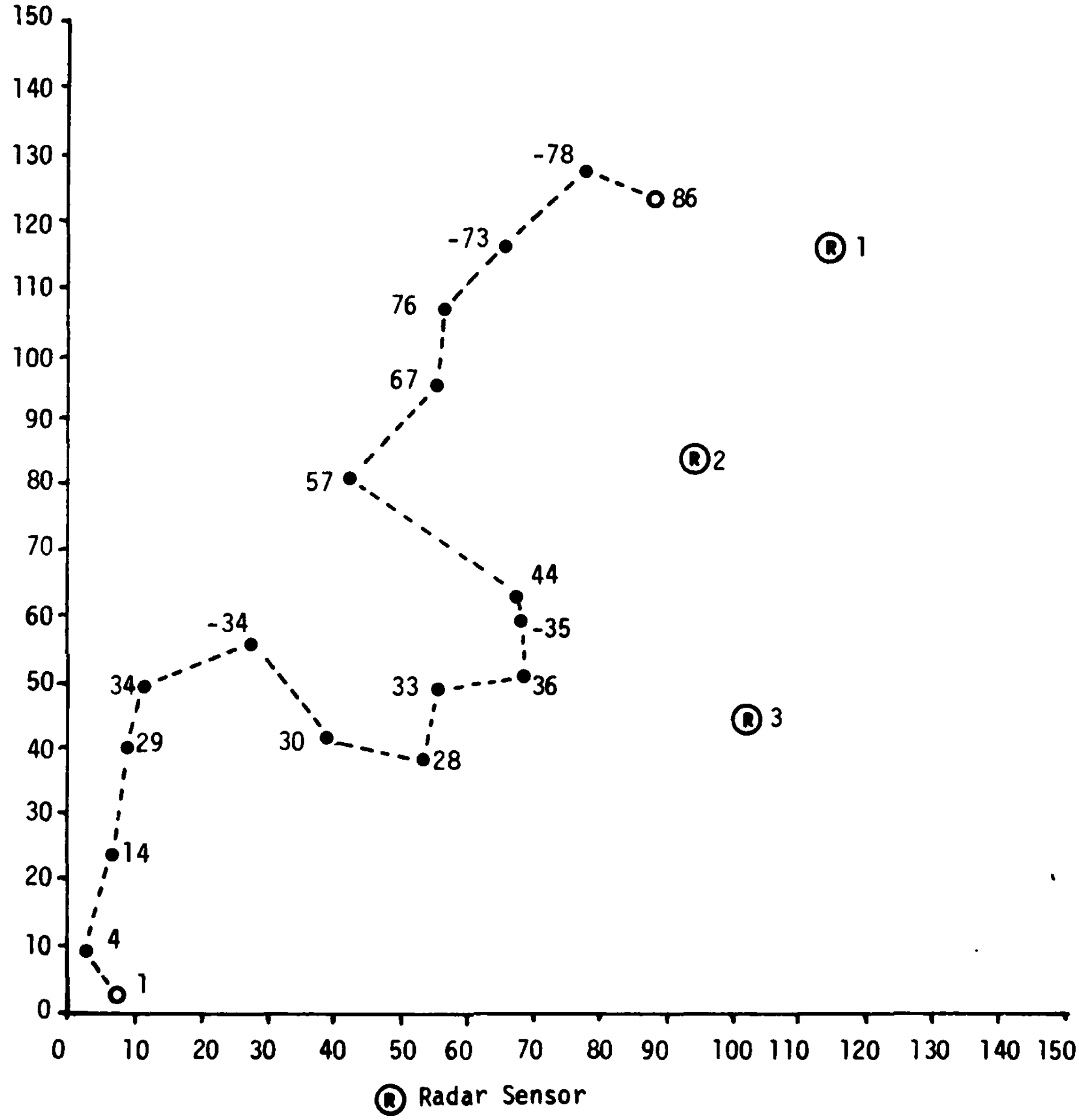

Figure 6.10. Case 3 - Refined Route.

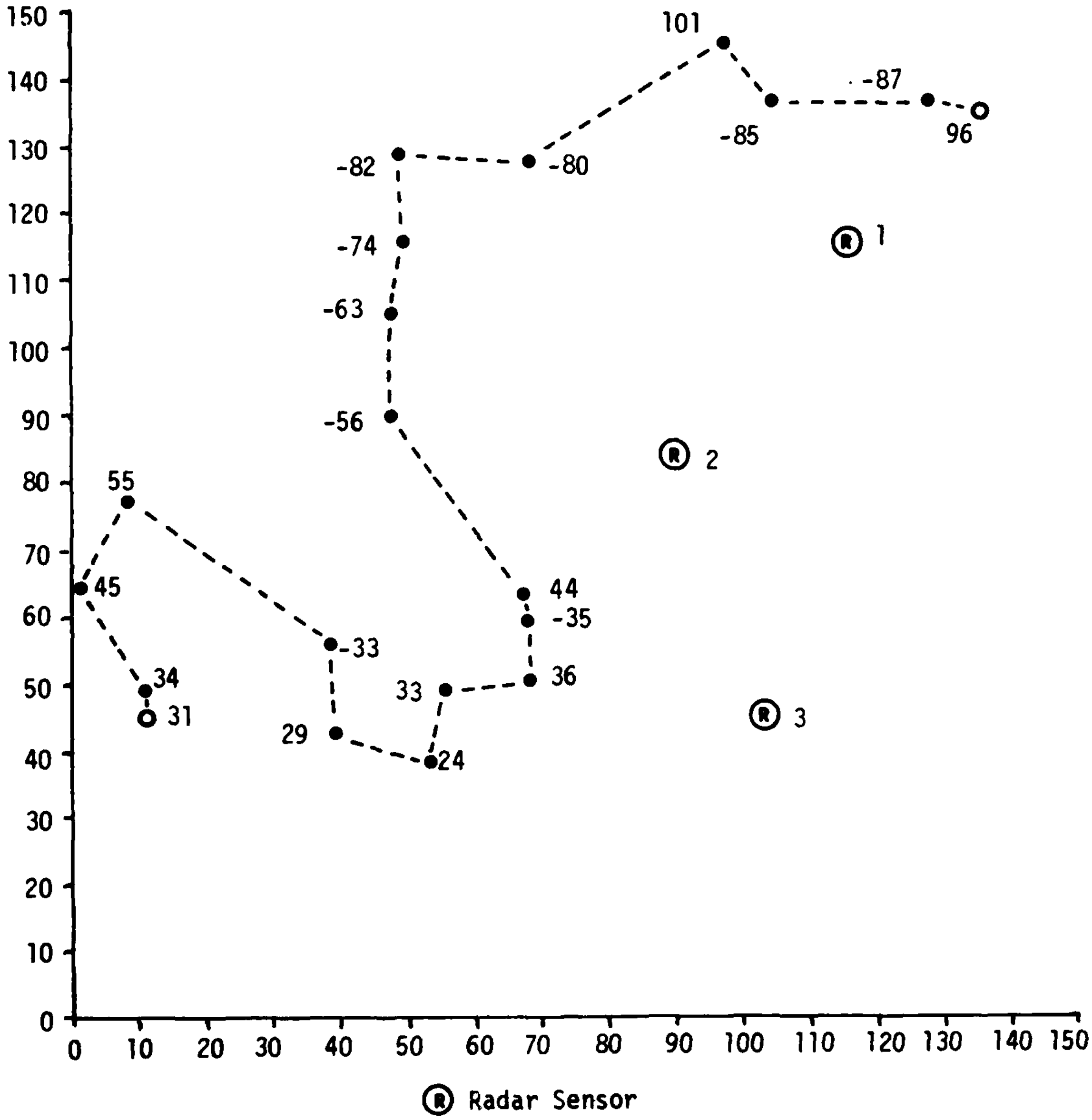

Figure 6.11. Case 4 - Refined Route.

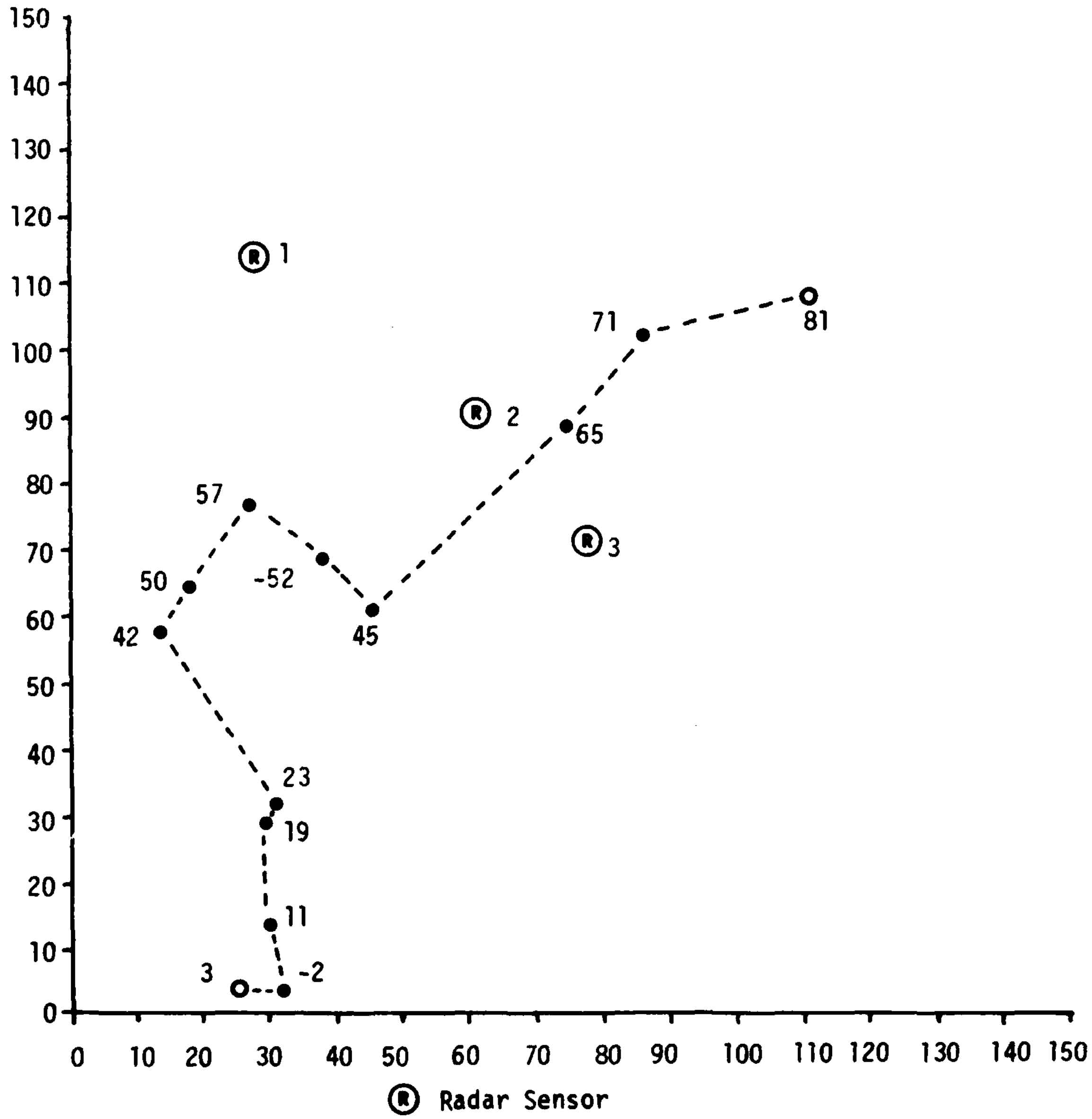

Figure 6.12. Case 5 - Refined Route.

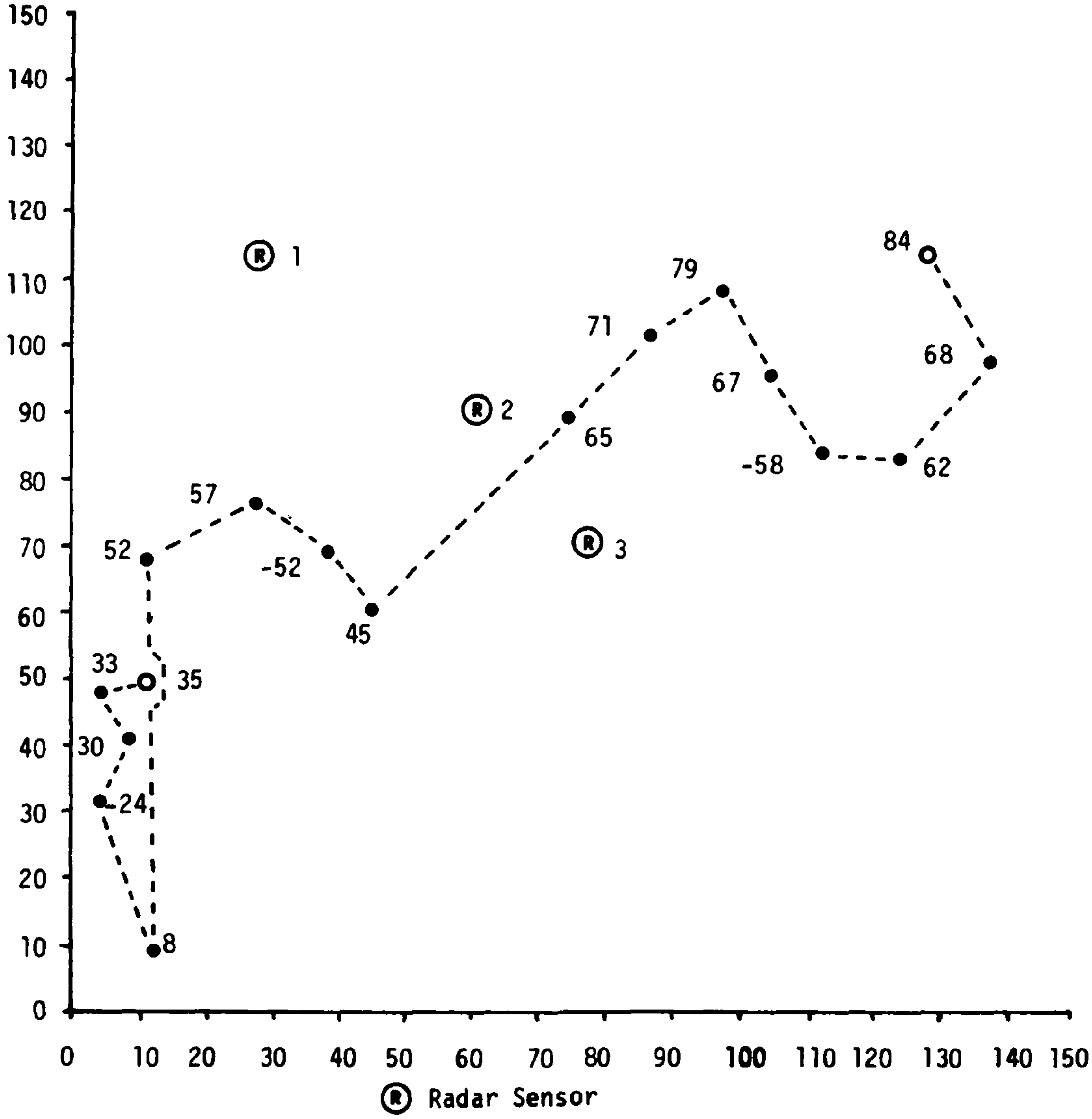

Figure 6.13. Case 6 - Refined Route.

shows considerable route improvement when these routes are refined. Figure 6.13 indicates that the route refinement is not perfect in that there is obvious improvement by proceeding directly from node 35 to node 52.

Case seven was the only route in area two that the initial route was acceptable. Only the first three nodes are eliminated in the refinement. For case eight, the initial node is located in a narrow valley forcing the route selection to proceed south. This direction is towards the air defenses causing the meandering in the route. The refinement caused the route selection to be across the valley entrance slope to achieve an acceptable route. The routes in Figures 6.14 and 6.15 are mostly along the base of the ridge. In Table 6.10 is a summary of the improvements in terms of nodes traversed.

Table 6.10 Route Improvement (Node Traversed)

Case	Initial	Final
1	25	25
2	32	24
3	26	18
4	57	20
5	37	13
6	51	17
7	20	16
8	39	15

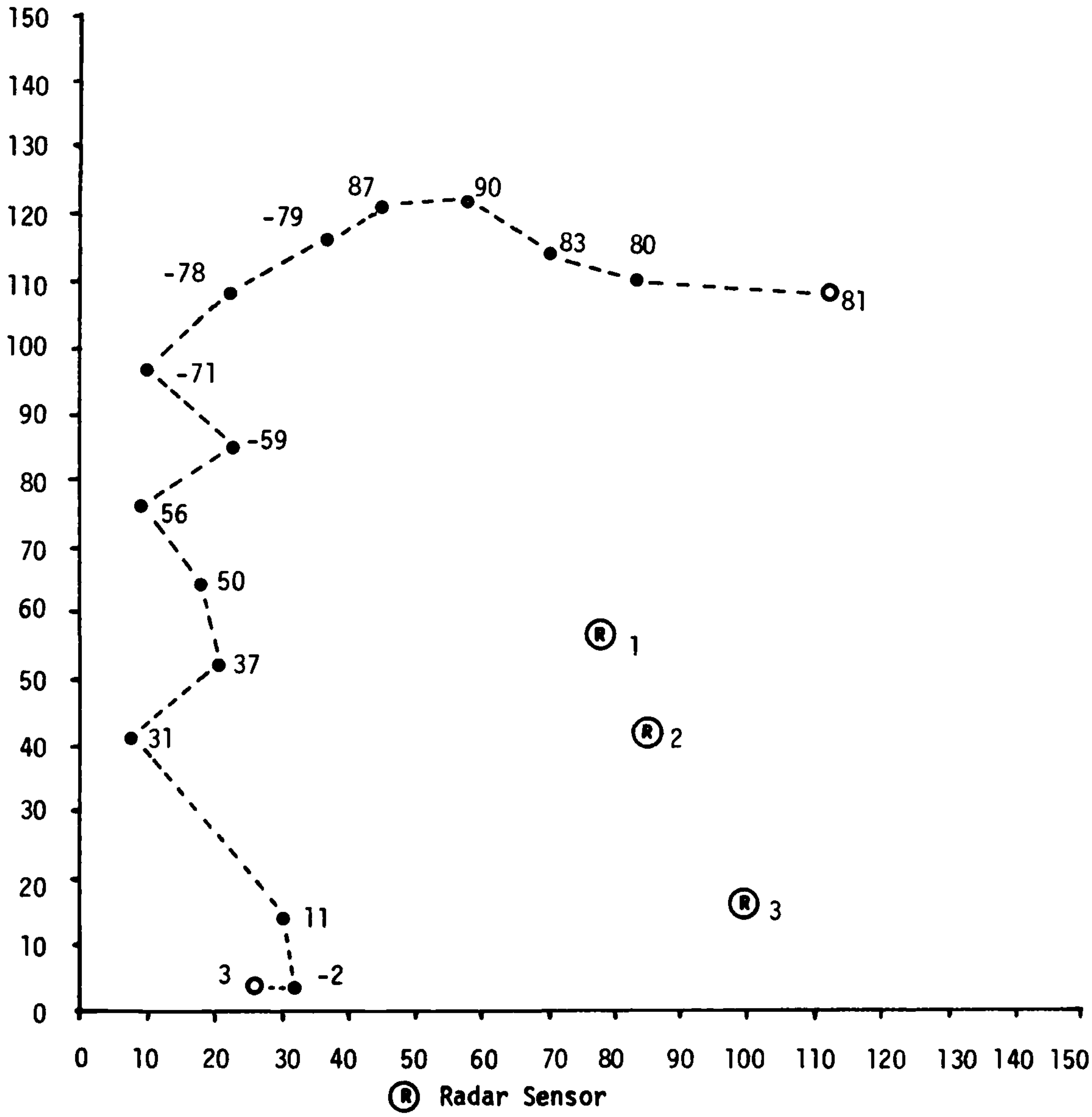

Figure 6.14. Case 7 - Refined Route.

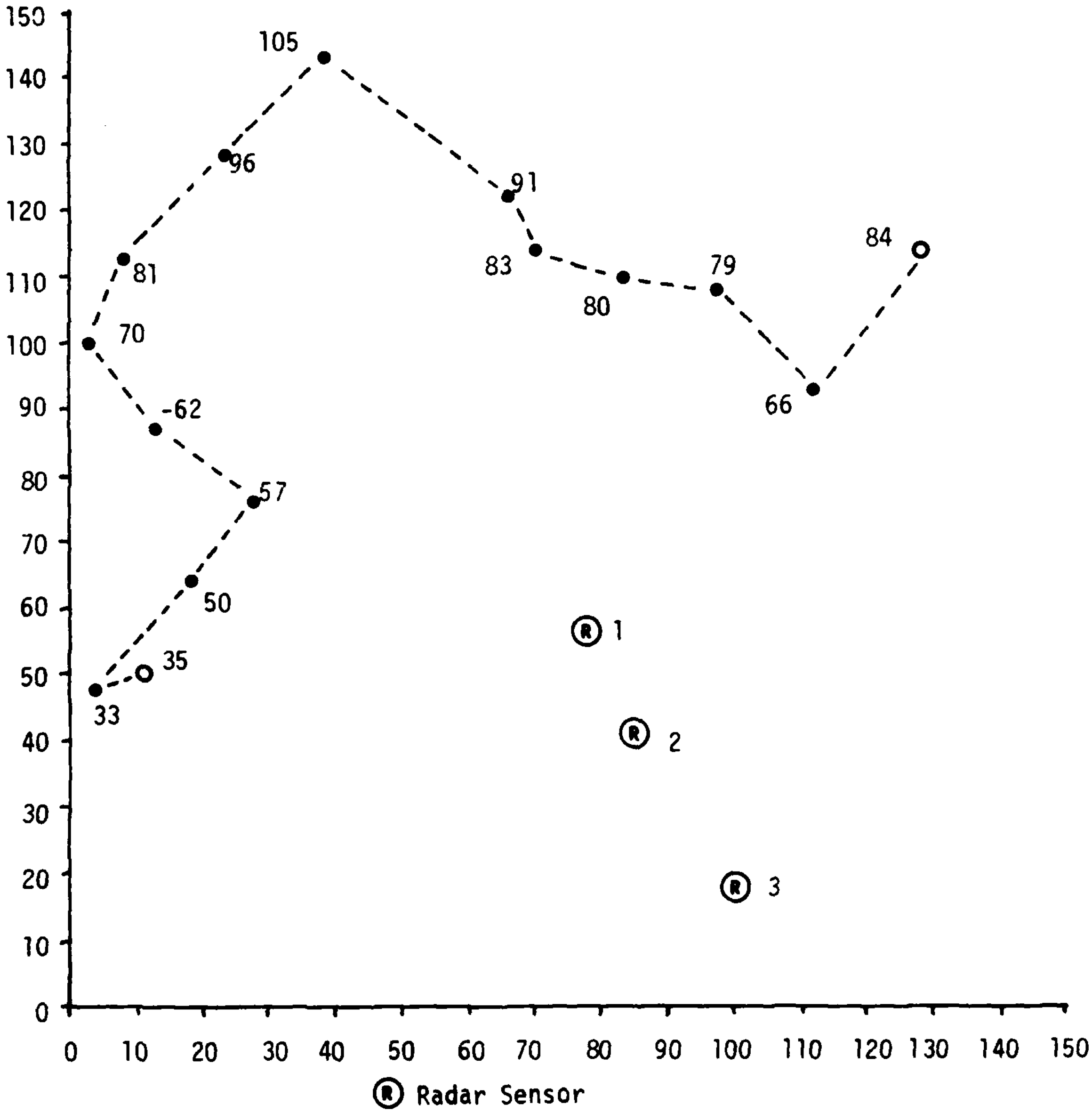

Figure 6.15. Case 8 - Refined Route.

6.4 Large Area Analysis

Several size terrain areas were utilized to evaluate the model's performance. The initial point was held constant and the destination and number of sensors were varied. Table 6.11 gives the location of the sensors and the size area where they were utilized. The areas ranged from 20 by 20 km to 35 by 35 km. The elevation varied from 270 to 610 meters for the 20 by 20 km case and varied from 270 to 850 meters for the 35 by 35 km cases. The limiting factor in the area size is computer core capacity.

The southwest corner of each area is the same. The larger size areas are obtained by increasing the x and y distance from this corner. The test area discussed in section 6.2 is the southwest 10 x 10 km sector of these larger areas. As one travels from the southwest to the northeast the terrain becomes progressively rougher. Thus, the routes were selected to travel this same direction. They begin in the southwest and end in the northeast sector. Since the areas are larger the lethal radius of the systems were increased to 6 km.

The large size of these areas resulted in voluminous output from the model. Therefore, the results are summarized rather than presented in detail as the small areas. The routes developed by the model had the same characteristics of the small areas. The route end points and the sensor deployment determined the smoothness of the route. The routes for all cases would begin fairly straight; however, the deployment of the sensors and terrain roughness would cause meandering of the route when it reached the central area of the 35 by 35 km case. The refinement process eliminated the doubling back as it had done in the small cases.

Table 6.11 Sensor Deployment

20-20 km Area		35-35 km Area	
Sensor	(X,Y,Z)	Sensor	(X,Y,Z)
1	(97, 280, 500)	1	(300, 414, 490)
2	(165, 250, 440)	2	(371, 214, 490)
3	(193, 71, 400)	3	(14, 314, 450)
25-25 km Area		4	(285, 328, 460)
Sensor	(X,Y,Z)	5	(228, 407, 520)
1	(97, 280, 500)	6	(285, 243, 450)
2	(165, 250, 440)	7	(200, 214, 410)
3	(193, 71, 400)	8	(336, 71, 350)
30-30 km Area		9	(364, 288, 530)
Sensor	(X,Y,Z)	10	(97, 280, 500)
1	(97, 280, 500)		
2	(336, 71, 350)		
3	(364, 288, 530)		

Table 6.12 provides an overall summary of the six large cases. The computer processing time for each of the cases indicates that terrain size significantly increases the run times for the model. The 30 by 30 km case, when compared to the 35 by 35 km case of three radars, indicates the deployment and route end points can produce very different results. The initial routes for these two cases are refined to approximately the same size. In all cases the refinement provided an improvement in route performance by reducing the penalty.

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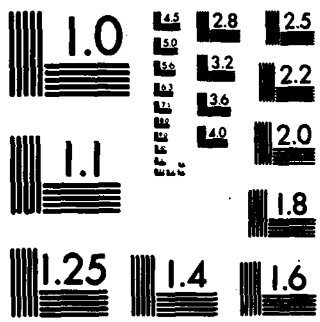

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Table 6.12 Large Area Cases

Area	Sensors	Low Nodes	High Nodes	Route Nodes	Penalty	Refined Nodes	Penalty	Run Time (sec)
20-20	3	415	389	63	6996	28	3510	79.5
25-25	3	648	624	218	17498	35	5086	114.1
30-30	3	938	918	458	44499	63	7793	155.1
35-35	3	1289	1258	181	12783	66	5325	187.6
35-35	5	1289	1258	331	29082	86	7097	216.9
35-35	10	1289	1258	466	95154	97	19942	284.3

CHAPTER VII

MODEL VALIDATION

7.1 Introduction

For the model to be of any utility, it must be tested and validated. A comparison is required between a tactician's route analysis and the heuristic model which attempts to approximate that analysis.

The test area has relatively flat terrain through the center region and high ground on the eastern edge and in the northwest corner. The hilly areas are difficult for the model logic to process into a smooth route line that an individual would expect to see for a route.

A tactician planning a route needs to visually perceive the relationship between the route initialization, positions to be avoided, and the final destination. The air defense sensors will be bypassed, if possible, by traveling around these positions outside their effective engagement limits. However, one tactician's ideal route may be another tactician's worst case. The manually produced route is a highly subjective analysis.

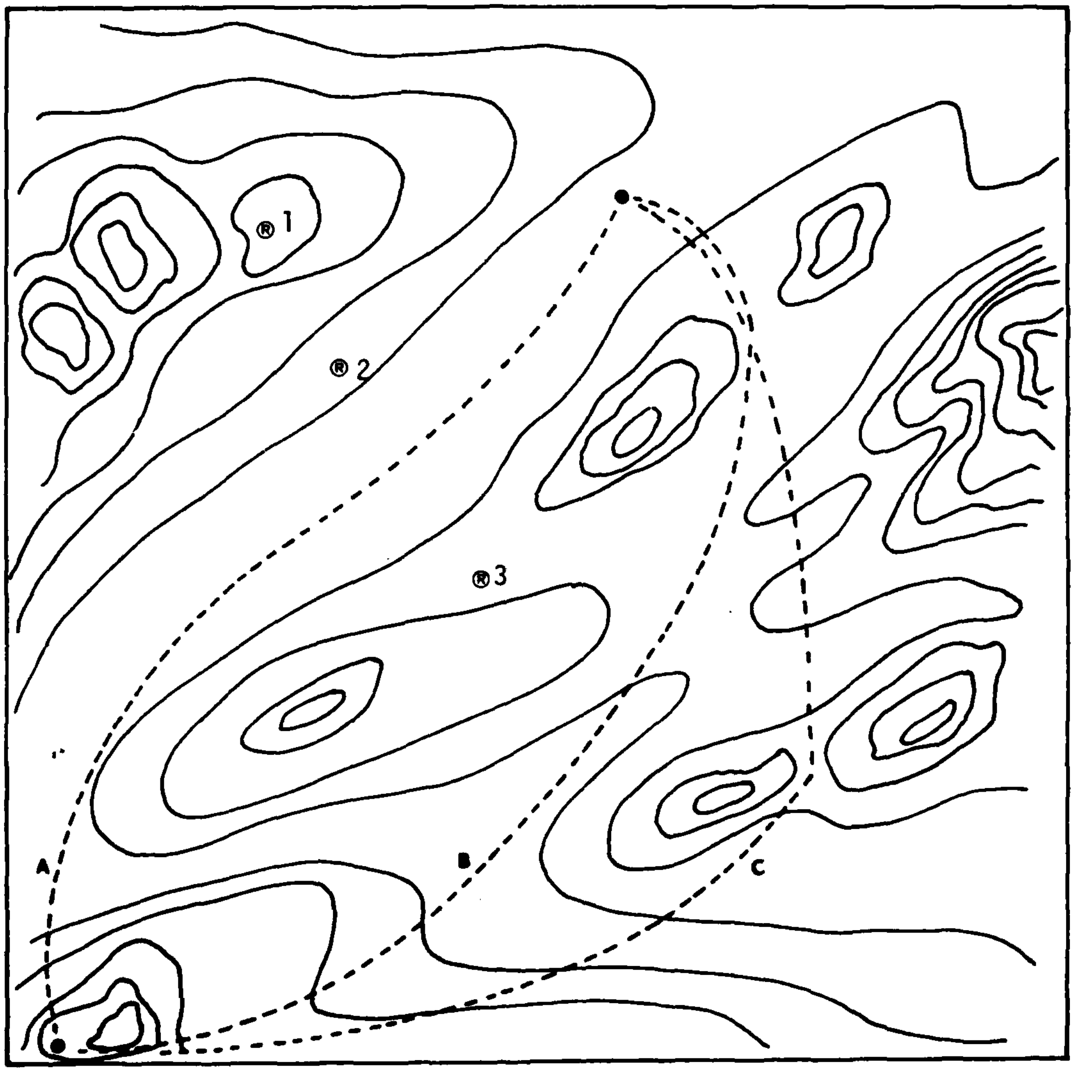
7.2 Manual Route Selection

The development of a route by manual analysis requires studying a topographic map of the appropriate area. The development of a low flying aircraft route dictates the type of information desired: The

location of the air defenses, the valleys, the hill tops, and the built-up areas is important. The information concerning the area is utilized in the route selection to avoid the air defenses and enemy concentrations.

The problem with reading a topographic map is trying to perceive the 3-dimension aspects of the terrain. Ordinarily, relief is shown by contour lines. For level terrain the contour lines are widely spaced whereas rough or hilly terrain will have densely packed contour lines. The rivers and streams give the location of valley floors and lowest points in flat terrain. One method for showing the vertical aspects of the terrain is to draw a profile of the elevation. Along a line between any two points the contour elevations are plotted, from which LOS can be determined and the degree of terrain roughness (see Figure 2.2). For a large area and even a modest number of points this approach is impractical.

Figure 7.1 depicts the terrain area used in the test case and indicates the relative position of the hills and valleys with the sensors. The routes shown in Figure 7.1 were developed by questioning analysts whose expertise is in air defense routing. Providing them with the location of the sensors and the route end points on a topographic map, the routes A, B, and C were chosen. If a direct route is required, route A is proposed since it follows the valley floor and passes midway between two of the sensors. If the sensors are to be avoided, routes B and C are chosen since they utilize the hills as masks and bypass



® Radar Sensor
A,B,C Routes

Figure 7.1. Terrain Area One.

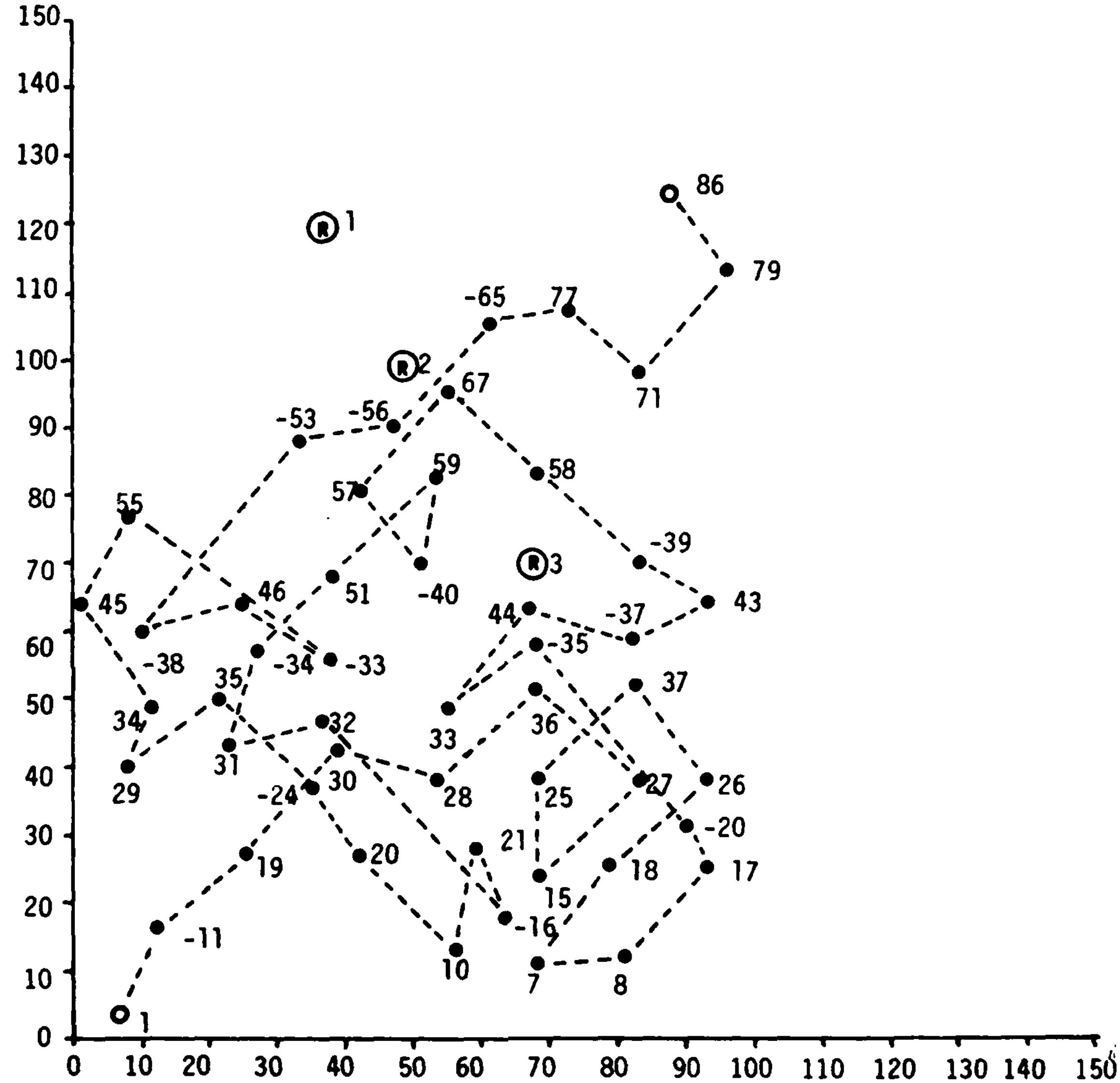
the sensors. Routes B and C are preferred by all the analysts. The question of model validity is whether or not similar routes are produced when the model uses its decision logic.

7.3 Model Route Selection

For development and testing of the model a 10 by 10 km area was selected from the 35 by 35 km data base that is representative of both relatively flat and hilly terrain. In the initial testing, the model would form a circuit through several nodes before returning to the starting node. After these first runs, decision logic was added in the form of weighting as described in Chapter IV. The major piece of information the model considers that the tactician has difficulty in assimilating is the LOS determination. The degree of visibility a node has with the sensors provides a basis upon which a quantitative selection can be made.

To test this hypothesis, the model was run with different levels of information available to the decision logic. With only the distance and height of neighboring nodes, the model produced a very irregular route. The model would exhaust the nodes in the neighborhood before leaving that immediate region for any new points (Figure 7.2).

With the exposure value of a node added to the decision logic, this second level of information allowed the model to produce a node linkage which resembled a route (Figure 7.3). The third level provided data on radar location and range with which the model was able to produce a route that approximates the route an individual analyst would



Radar Sensor

Figure 7.2. Minimal Information Route.

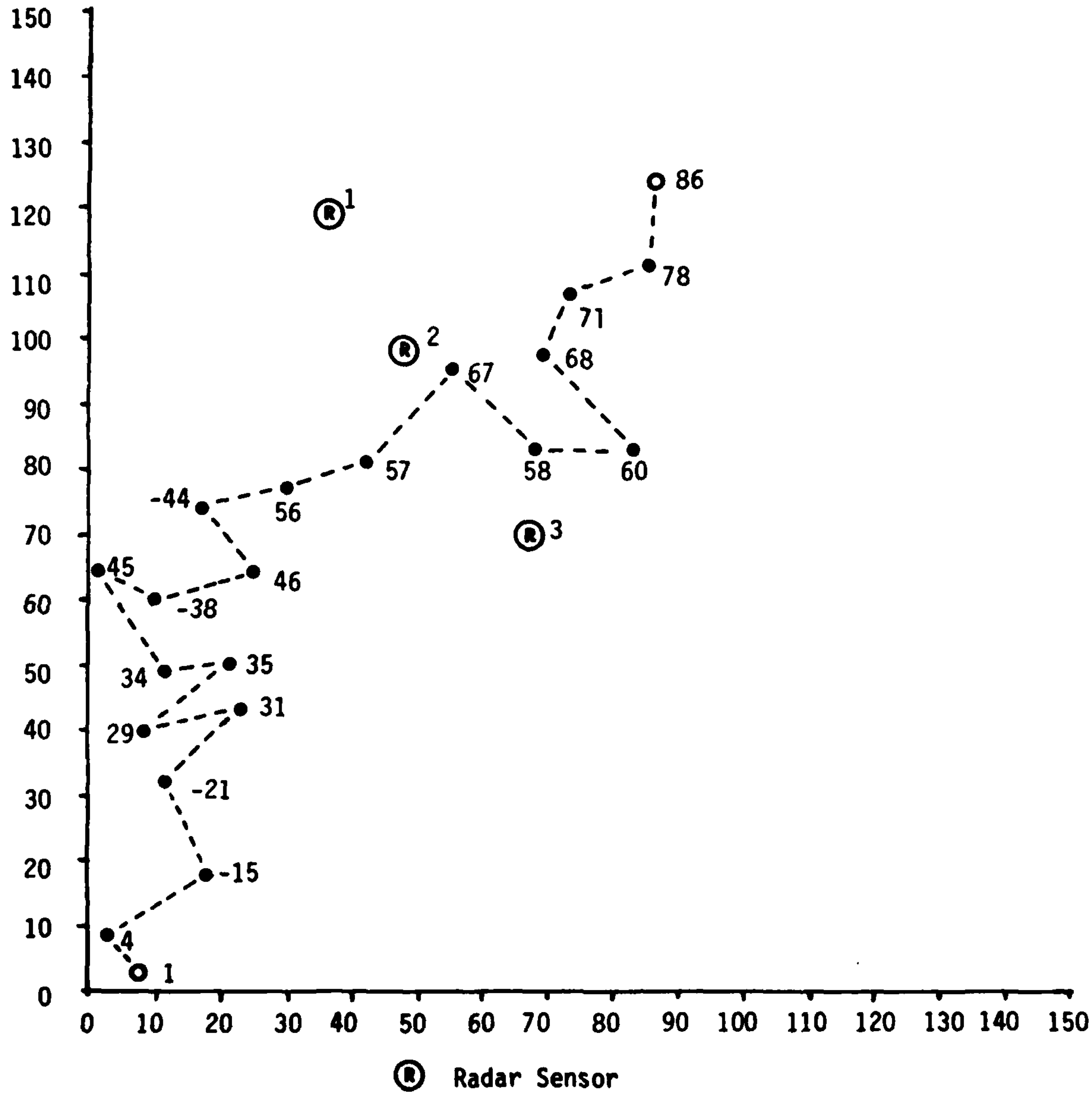


Figure 7.3. Exposure Value Route.

select (Figure 7.4). In Figure 7.4 the radars are deployed in the northern sector and the route avoids them by a southerly route.

When the destination is within 1 km of the current position the final terminal weighting forces the choice of the next position to be the destination or an intermediate node. Normal attacking procedures have some distance from target at which the attack is committed and one proceeds directly towards the target. With high speed aircraft (250 m/sec) this attack point is 3 to 6 km away depending on the type of ordnance being used. Stand-off munitions exist that allow the attacking aircraft to be 20 or more km away when releasing their ordnance, if the target is heavily defended.

The results of the model are a series of linked points which comprise a route. A comparison of Figure 7.4 with Figure 7.1 indicates that the preferred route C is approached with the radar avoidance weighting. The degree of match between the model route and the manual route give a visual indication of acceptability.

7.4 Model Evaluation

The exposure value of each route node point was used as a basis of comparison. Since the routes are not of equal length, the exposure of the node links were used to establish the exposure value of a route. The calculation of route exposure is given below:

$$EVR = \sum_{i=1}^{n-1} EV(N_{i+1}) \left[\frac{d_{i+1}}{D} \right]$$

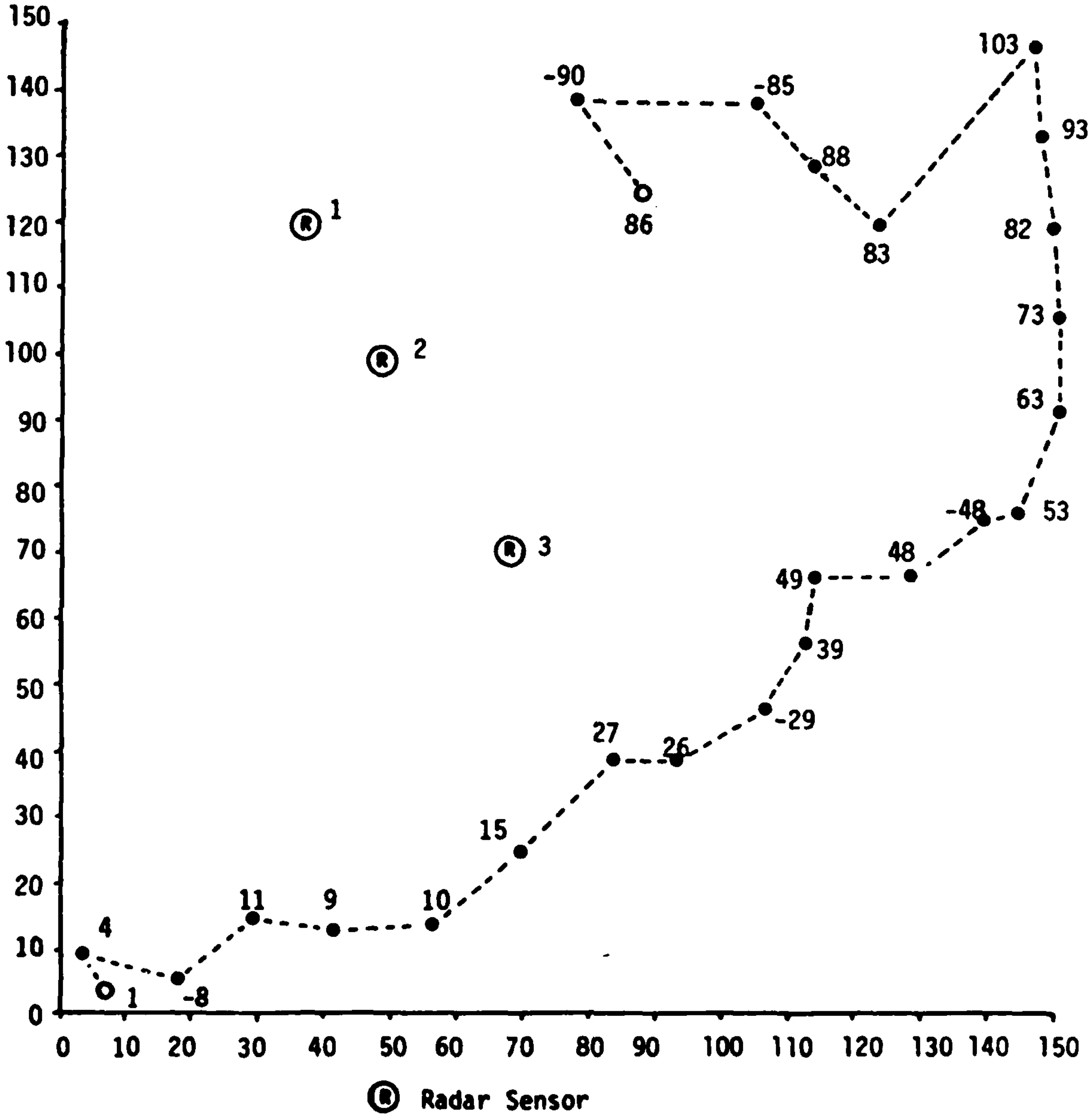


Figure 7.4. Complete Information Route.

$$\text{where} \quad D = \sum_{i=1}^{n-1} d_{i+1} \,,$$

D = The total length of the route,

$EV(N_{i+1})$ = The exposure value of route node i+1,

d_{i+1} = The distance from node i to node i+1,

EVR = The exposure value of the route.

Utilizing this relation the model routes can be compared with the manually chosen routes. The scenario for the manual selection and the model is Case 1. In Table 7.1 the route exposure values are given for the three manual routes and the model route. The preferred route C and the model route achieved an exposure value of 0.844 and 0.888 respectively.

The other routes that were developed by the model indicate that the deployment of the sensors within the terrain have a definite effect on the selection process. Rough terrain with sensors deployed to cover the low elevation corridors is the most difficult case for the model to evaluate and select a minimum exposure, minimum elevation route for penetrating the air defenses.

Table 7.1 Route Exposure Values

Route	EVR
A	1.582
B	1.325
C	0.844
Model	0.888

CHAPTER VIII

CONCLUSIONS AND RECOMMENDATIONS

8.1 Conclusions

This research has addressed an area of air defense modeling which is normally analyzed visually with topographic maps and coverage diagrams before any tactical gaming is performed. A significant problem in analyzing terrain from a topographic map is perceiving the 3-dimensional aspects of terrain features. The degree of visibility a manually developed route will have can only, at best, be estimated. Any route selected is based on the particular individual's ability to be a good tactician. Using the subjective route for air defense modeling adds an unknown to the war gaming results.

The model that has been presented overcomes the shortcomings cited above and provides a minimum-exposure, minimum-elevation route. The developed route then serves as a baseline from which other flight paths can be evaluated. The model provides the visibility or exposure of all the high and low elevation nodes within the area. These values can be used as a reference for evaluating the visibility of specific areas of the terrain in addition to route identification.

Terrain roughness has a marked effect in the developed route. By placing the radar sensors at key positions to cover approach corridors, the model develops long routes in searching for a minimum exposure route. The long routes indicate the problem of traversing an area undetected by modern air defenses. The addition of more sensors

increases the penalty associated with travel through an area and also increases the route length. In the 35 by 35 km case the penalty value increased from 12783 for the three radar case to 95154 for the ten radar case. The route nodes also varied from 181 to 466 in the initial routes.

8.2 Recommendations for Further Research

In testing this model it became very obvious that minor changes in weighting of a single node point would result in an entirely different route. Further research is needed into the sensitivity of the weighting scheme utilized in this model.

The decision logic that is used in this model is by no means the only one that should be used. There needs to be the ability to enter check points through which the route must pass on its way to the destination. Along this same line of reasoning, the model could be modified to evaluate a proposed route rather than find the route.

The idea of limiting the next node selection to a neighborhood about the current position could be expanded to other problems besides air defense aircraft routes. The routing of oil and gas pipelines could be analyzed using the model. The radar sites could be a town or built up areas to be avoided. The weighting of the height penalty could be increased to favor level terrain.

Lastly, the author hopes that this research might serve as a start for further effort into the general problem of routing.

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APPENDICES

APPENDIX A

ROUTING PROBLEMS

Within this appendix are the data tables for the additional problem cases discussed in Chapter 6. Each set of tables is preceded by a page identifying the case. The tables for exposure values in these cases were not included for the sake of brevity.

Case 2 - Area 1, Route 2, Sensor set 1.

Table A.1. Case 2 - Node Linkage for Route

FROM	EASTING	NORTHING	TO	PENALTY	EASTING	NORTHING
31	770	10150	30	26	1610	10010
30	1610	10010	28	74	560	9800
28	560	9800	35	2	1470	10500
35	1470	10500	34	164	770	10430
34	770	10430	45	1	70	11480
45	70	11480	-38	164	700	11200
-38	700	11200	-42	260	560	12040
-42	560	12040	-52	231	560	13090
-52	560	13090	-44	97	1190	12180
-44	1190	12160	46	188	1750	11480
46	1750	11460	-33	214	2660	10920
-33	2660	10920	32	354	2590	10290
32	2590	10290	-22	452	3290	9240
-22	3250	9240	29	145	2730	9940
29	2730	9940	24	232	3710	9660
24	3710	9660	25	243	4760	9660
25	4760	9660	33	228	3650	10430
33	3850	10430	36	295	4760	10570
36	4760	10570	37	240	5810	10640
37	5810	10640	38	198	6510	10780
38	6510	10780	43	298	6580	11410
43	6580	11410	52	278	6580	12320
52	6580	12320	61	265	7560	13230
61	7560	13230	-46	252	8540	12250
-46	8540	12250	54	87	9380	12320
54	9360	12320	53	56	10050	12320
53	10080	12320	63	71	10500	13370
63	10500	13370	73	27	10500	14350
73	10500	14350	82	57	10430	15330
82	10430	15330	92	96	10290	16240
92	10290	16240	96	285	9450	16450

Table A.2. Case 2 - Node Linkage

```
NODE NO.   31 TOTAL LINKS     7
X,Y,Z COORDINATE    11,   45,  280
LINKED TO        34      28      35      30     -21     -23     -38
EXPOSURE        100      53      34      25     161     241     160
WEIGHTED        101     168      70      26     324     242     161

NODE NO.   30 TOTAL LINKS     9
X,Y,Z COORDINATE    23,   43,  280
LINKED TO        35      34      32      28     -23     -24     -34     -21     -33
EXPOSURE        100      51     118      36     356     280     343     186     306
WEIGHTED        101     104     238      74     714     281     688     374     618

NODE NO.   28 TOTAL LINKS     4
X,Y,Z COORDINATE     8,   40,  280
LINKED TO        34      35     -21     -23
EXPOSURE         88       0     258     295
WEIGHTED        178       2     516     296

NODE NO.   35 TOTAL LINKS     6
X,Y,Z COORDINATE    21,   50,  280
LINKED TO        34      46     -34     -38     -23     -24
EXPOSURE         91     258     373     203     274     213
WEIGHTED        184     518     742     408     550     214

NODE NO.   34 TOTAL LINKS     3
X,Y,Z COORDINATE    11,   49,  280
LINKED TO        45     -38     -23
EXPOSURE          0     254     180
WEIGHTED          1     255     181

NODE NO.   45 TOTAL LINKS     3
X,Y,Z COORDINATE     1,   64,  300
LINKED TO        55     -38     -42
EXPOSURE        228     163     211
WEIGHTED        456     164     424

NODE NO.  -38 TOTAL LINKS     3
X,Y,Z COORDINATE    10,   60,  310
LINKED TO        46     -42     -44
EXPOSURE        151     259     165
WEIGHTED        304     260     332

NODE NO.  -42 TOTAL LINKS     3
X,Y,Z COORDINATE     9,   72,  330
LINKED TO        55     -44     -52
EXPOSURE        279     126     230
WEIGHTED        280     254     231

NODE NO.  -52 TOTAL LINKS     5
X,Y,Z COORDINATE     8,   57,  350
LINKED TO        55      70     -54     -44     -59
EXPOSURE        270     313     339      96     246
WEIGHTED        542     314     680      97     494

NODE NO.  -44 TOTAL LINKS     5
X,Y,Z COORDINATE    17,   74,  330
LINKED TO        55      46      56     -43     -54
EXPOSURE        339     167     208     251     242
WEIGHTED        620     168     418     504     486

NODE NO.   46 TOTAL LINKS     5
X,Y,Z COORDINATE    25,   64,  300
LINKED TO        51      56     -34     -43     -33
EXPOSURE        250     266     306     360     213
WEIGHTED        502     534     614     722     214

NODE NO.  -33 TOTAL LINKS     6
X,Y,Z COORDINATE    39,   56,  300
LINKED TO        32      51      29     -35     -34     -40
EXPOSURE        176     395     177     404     381     335
WEIGHTED        354     792     355     810     764    3360
```

Table A.2. (cont'd.)

```
NODE NO.   32 TOTAL LINKS     5
X,Y,Z COORDINATE   37.   47.  280
LINKED TO        29    -24    -34    -36    -22
EXPOSURE        227    251    332    332    225
WEIGHTED        456    584    666    666    452

NODE NO.  -22 TOTAL LINKS     6
X,Y,Z COORDINATE   47.   32.  290
LINKED TO        18     24     20     29    -24    -14
EXPOSURE        315    268    190    144    243    247
WEIGHTED        632    538    191    145    488    496

NODE NO.   29 TOTAL LINKS     5
X,Y,Z COORDINATE   39.   42.  280
LINKED TO        24     18     15    -24    -34
EXPOSURE        231    252    253    329    310
WEIGHTED        232    506    508    660    311

NODE NO.   24 TOTAL LINKS     6
X,Y,Z COORDINATE   53.   36.  280
LINKED TO        33     20     25     18     36    -34
EXPOSURE  [illegible]  265    242    307    209    416
WEIGHTED  [illegible]  532    243    616   2100   1234

NODE NO.   25 TOTAL LINKS     8
X,Y,Z COORDINATE   68.   38.  280
LINKED TO        36     20     13     27     17     33     37    -24
EXPOSURE        309    269    258    270    249    227    275    369
WEIGHTED       3100    540    518    271    500    228    276    740

NODE NO.   33 TOTAL LINKS     4
X,Y,Z COORDINATE   55.   49.  280
LINKED TO        36     44    -36    -35
EXPOSURE        294    278    418    303
WEIGHTED        295   2790    419   3040

NODE NO.   36 TOTAL LINKS     6
X,Y,Z COORDINATE   68.   51.  280
LINKED TO        44     37     47     27    -35    -37
EXPOSURE        397    239    337    176    414    331
WEIGHTED       3880    240   3380    354   4150    332

NODE NO.   37 TOTAL LINKS     7
X,Y,Z COORDINATE   83.   52.  280
LINKED TO        38     42     27     43     26    -37    -35
EXPOSURE        197    363    209    364    166    400    320
WEIGHTED        196    364    418    305    334   4010   3210

NODE NO.   38 TOTAL LINKS     5
X,Y,Z COORDINATE   93.   54.  280
LINKED TO        43     42    -37    -29    -28
EXPOSURE        297    250    258    245    258
WEIGHTED        298   2510   2590    492    518

NODE NO.   43 TOTAL LINKS     5
X,Y,Z COORDINATE   94.   63.  290
LINKED TO        42     52    -37    -39    -47
EXPOSURE        311    277    262    290    286
WEIGHTED       3120    278    526   2910    287

NODE NO.   52 TOTAL LINKS     8
X,Y,Z COORDINATE   94.   76.  300
LINKED TO        60     62     42     61    -45    -47    -50    -39
EXPOSURE        291    277    231    264    354    335    342    288
WEIGHTED        584    278    464    265    710    336    343   2890

NODE NO.   61 TOTAL LINKS     9
X,Y,Z COORDINATE  109.   89.  330
LINKED TO        66     72    -51    -50    -60    -62    -47    -45    -46
EXPOSURE        339    227    346    341    315    313    285    287    125
WEIGHTED        340    456    694    684    316    314    572    576    252
```

Table A.2.(cont'd.)

```
NODE NO.  -46 TOTAL LINKS     6
X,Y,Z COORDINATE  122,   75,  330
LINKED TO           48      54      49     -45     -51     -55
EXPOSURE           146      86     234     330     328     237
WEIGHTED           294      87     470     662     329     238

NODE NO.   54 TOTAL LINKS     6
X,Y,Z COORDINATE  134,   76,  310
LINKED TO           53      48      50     -48     -55     -57
EXPOSURE            55     103      90     110     234     224
WEIGHTED            56     208     182     222     235     225

NODE NO.   53 TOTAL LINKS     5
X,Y,Z COORDINATE  144,   76,  300
LINKED TO           50      63     -48     -57     -55
EXPOSURE           128      70     110     246     215
WEIGHTED           258      71     222     247     216

NODE NO.   63 TOTAL LINKS     5
X,Y,Z COORDINATE  150,   91,  360
LINKED TO           73     -57     -61     -55     -58
EXPOSURE            26     259     283     176     235
WEIGHTED            27     600     284     354     472

NODE NO.   73 TOTAL LINKS     7
X,Y,Z COORDINATE  150,  105,  360
LINKED TO           82     -69     -61     -67     -58     -57     -55
EXPOSURE            56     322     312     266     270     241     187
WEIGHTED            57     323     626     534     542     484     376

NODE NO.   82 TOTAL LINKS     5
X,Y,Z COORDINATE  149,  119,  340
LINKED TO           92     -77     -69     -76     -67
EXPOSURE            95     204     288     161     221
WEIGHTED            96     205     576     162     444

NODE NO.   92 TOTAL LINKS     5
X,Y,Z COORDINATE  147,  132,  330
LINKED TO           96     103     -77     -92     -76
EXPOSURE           284      61     249     146     155
WEIGHTED           285   18600     750   14700   46600
```

Case 3 - Area 1, Route 1, Sensor Set 2.

Table A [illegible]

FROM	EASTING	[illegible]			[illegible]	[illegible]
1	[illegible]	[illegible]			[illegible]	[illegible]
-11	[illegible]	[illegible]			[illegible]	[illegible]
19	1796	[illegible]			[illegible]	[illegible]
30	2790	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
28	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]
36	4766	[illegible]		[illegible]	[illegible]	[illegible]
37	5010	[illegible]	[illegible]	[illegible]	[illegible]	9660
26	6510	9660	[illegible]	110	5530	8020
18	5530	8020	[illegible]	[illegible]	4760	9660
25	4760	9660	33	[illegible]	3090	10430
43	3090	[illegible]	[illegible]	[illegible]	[illegible]	11130
-35	4760	11130	47	167	3920	11550
47	3920	11550	44	111	4690	11410
44	4690	11410	43	[illegible]	6500	11410
43	6500	11410	-47	99	7280	12250
-47	7280	12250	52	65	6500	12320
52	6580	12320	60	[illegible]	5810	12810
60	5810	12810	-41	176	4760	11970
-41	4760	11970	-37	186	5740	11130
-37	5740	11130	38	2	6510	10780
38	6510	10780	42	162	5880	11410
42	5880	11410	49	65	7910	11620
49	7910	11620	48	32	8960	11620
48	8960	11620	50	30	10010	11760
50	10010	11760	54	99	9380	12320
54	9380	12320	-46	70	8540	12250
-46	8540	12250	-55	172	9450	13300
-55	9450	13300	53	66	10080	12320
53	10080	12320	63	62	10500	13370
63	10500	13370	73	27	10500	14350
73	10500	14350	82	36	10430	15330
82	10430	15330	93	65	10290	16240
93	10290	16240	103	64	10220	17220
103	10220	17220	-92	177	9800	17010
-92	9800	17010	-93	180	8050	17080
-93	8050	17080	-85	254	7280	16590
-85	7280	16590	92	157	6370	16030
92	6370	16030	86	282	6090	15680

Table A.4. Case 3 - Node Linkage

```
NODE NO.    1 TOTAL LINKS     4
X,Y,Z COORDINATE     7.     3.   270
LINKED TO          4     -6     -8    -11
EXPOSURE          85    223    173     67
WEIGHTED          86    224    174     68

NODE NO.  -11 TOTAL LINKS     6
X,Y,Z COORDINATE    12.    16.   330
LINKED TO         14      4     19    -15     -6     -8
EXPOSURE          95     52     40    174    170    171
WEIGHTED          96    106     41    175    342    344

NODE NO.   19 TOTAL LINKS     7
X,Y,Z COORDINATE    23.    27.   300
LINKED TO         11     30    -23    -15    -13    -24    -21
EXPOSURE         154     53    180    221    173    123    103
WEIGHTED         310     54    181    444    348    124    208

NODE NO.   30 TOTAL LINKS     7
X,Y,Z COORDINATE    35.    42.   280
LINKED TO         32     28     20    -24    -22    -33    -34
EXPOSURE         154     91    123    189    146    150    179
WEIGHTED         155     92    248    380    294    151    180

NODE NO.   28 TOTAL LINKS     6
X,Y,Z COORDINATE    53.    32.   280
LINKED TO         33     21     25     20     36    -22
EXPOSURE         140    126    105    176     70    243
WEIGHTED         141    254    106    354     71    468

NODE NO.   36 TOTAL LINKS     8
X,Y,Z COORDINATE    66.    51.   280
LINKED TO         44     25     33     37     47     27    -35    -37
EXPOSURE         232    120    120    115    173     65    265    201
WEIGHTED         233    242    242    116    348    132    266    202

NODE NO.   37 TOTAL LINKS     8
X,Y,Z COORDINATE    83.    52.   280
LINKED TO         38     42     27     43     26     25    -37    -35
EXPOSURE          76    242    114    127     24     62    269    194
WEIGHTED          77    486    233    128     50    126    270    195

NODE NO.   26 TOTAL LINKS     7
X,Y,Z COORDINATE    93.    35.   280
LINKED TO         27     17     18    -20    -28    -29    -18
EXPOSURE         143    128     57    181    210    115    122
WEIGHTED         144    258    116    364    211    116    246

NODE NO.   18 TOTAL LINKS     9
X,Y,Z COORDINATE    75.    26.   280
LINKED TO         15     27     17      8     25      7    -20    -12    -16
EXPOSURE         154    136    160    150     90     94    187    192    115
WEIGHTED         310    137    161    302     91    190    186    386    234

NODE NO.   25 TOTAL LINKS     5
X,Y,Z COORDINATE    68.    38.   280
LINKED TO         21     15     27     33    -12
EXPOSURE         154    148    149    126    474
WEIGHTED         310    298    150    127    950

NODE NO.   33 TOTAL LINKS     3
X,Y,Z COORDINATE    55.    49.   280
LINKED TO         44    -36    -35
EXPOSURE          75    255    106
WEIGHTED         152    256    107

NODE NO.  -35 TOTAL LINKS     5
X,Y,Z COORDINATE    68.    59.   290
LINKED TO         44     47    -41    -37    -35
EXPOSURE         175    106    215    110    176
WEIGHTED         176    107    216    111    354
```

Table A.4. (cont'd.)

```
NODE NO.   47 TOTAL LINKS     4
X,Y,Z COORDINATE   56.   65.  290
LINKED TO        44     -40     -36     -41
EXPOSURE        110     260     209     170
WEIGHTED        111     261     420     342

NODE NO.   44 TOTAL LINKS    21
X,Y,Z COORDINATE   67.   63.  290
LINKED TO        42      58      59      60      43      38      51      27      52      57
LINKED TO        32      62      65     -41     -37     -40     -35     -36     -49     -33
LINKED TO       -56
EXPOSURE        183     207     237     197      68      34     195      93      90     202
EXPOSURE         67     168     216     243     185     202     219     190     220     149
EXPOSURE        233
WEIGHTED        184     209    2380     396      65      70     392     188     910     203
WEIGHTED        136     338    2170     244     186     203    2190     382     442     300
WEIGHTED       2340

NODE NO.   43 TOTAL LINKS     6
X,Y,Z COORDINATE   94.   63.  290
LINKED TO        38      42      52     -37     -39     -47
EXPOSURE        100     186      79     143     163      98
WEIGHTED        202     187     800     288     164      99

NODE NO.  -47 TOTAL LINKS     8
X,Y,Z COORDINATE  104.   75.  330
LINKED TO        52      49      61      62     -50     -45     -51     -49
EXPOSURE         62      42     172      98     268     149     220     139
WEIGHTED         63      86     356     990    2690     300     221    1400

NODE NO.   52 TOTAL LINKS     7
X,Y,Z COORDINATE   94.   76.  300
LINKED TO        50      62      42      61     -49     -50     -35
EXPOSURE        156     162     101     169     232     243     153
WEIGHTED        157    1630     204     340    2330     244     308

NODE NO.   60 TOTAL LINKS     6
X,Y,Z COORDINATE   63.   83.  300
LINKED TO        62      58      58     -49     -39     -41
EXPOSURE        172     122     151     284     141      84
WEIGHTED       1730     246     304    2650     284     170

NODE NO.  -41 TOTAL LINKS     4
X,Y,Z COORDINATE   68.   71.  300
LINKED TO        58      59     -39     -37
EXPOSURE        273     219     234      89
WEIGHTED        274    2200     235     180

NODE NO.  -37 TOTAL LINKS     3
X,Y,Z COORDINATE   82.   59.  290
LINKED TO        42      38     -39
EXPOSURE        229       0     194
WEIGHTED        230       2     390

NODE NO.   38 TOTAL LINKS     3
X,Y,Z COORDINATE   93.   54.  280
LINKED TO        42     -29     -28
EXPOSURE        151      98     167
WEIGHTED        182     198     336

NODE NO.   42 TOTAL LINKS    13
X,Y,Z COORDINATE   84.   63.  290
LINKED TO        27      58      62      39      49      61      24     -39     -49     -29
LINKED TO       -50     -28     -45
EXPOSURE        110     158     169      65      64     185      32     218     208     104
EXPOSURE        227     189     123
WEIGHTED        222     318     340     132      65     372      66     438    2090     210
WEIGHTED       2280     380     124

NODE NO.   45 TOTAL LINKS     6
X,Y,Z COORDINATE  113.   66.  300
LINKED TO        39      48      41     -45     -46     -50
EXPOSURE         85      15      31     197     120     188
WEIGHTED        172      32      64     198     121    1850

NODE NO.   48 TOTAL LINKS     8
X,Y,Z COORDINATE  128.   66.  300
LINKED TO        41      54      50     -46     -32     -48     -45     -31
EXPOSURE        124      81      24     137     126      57      95      73
WEIGHTED        250      82      80     276     254      58     200     148
```

Table A.4. (cont'd)

NODE NO. 90 TOTAL LINKS 6
X,Y,Z COORDINATE 143. 68. 300

LINKED TO	53	40	54	-48	-31	-32
EXPOSURE	100	90	98	132	135	96
WEIGHTED	101	182	99	133	272	154

NODE NO. 54 TOTAL LINKS 5
X,Y,Z COORDINATE 134. 76. 310

LINKED TO	53	-48	-46	-55	-57
EXPOSURE	55	110	69	169	168
WEIGHTED	112	222	70	170	169

NODE NO. -46 TOTAL LINKS 4
X,Y,Z COORDINATE 122. 75. 330

LINKED TO	61	-45	-51	-55
EXPOSURE	91	124	219	171
WEIGHTED	920	250	2200	172

NODE NO. -55 TOTAL LINKS 8
X,Y,Z COORDINATE 135. 90. 370

LINKED TO	69	63	53	73	-57	-58	-61	-48
EXPOSURE	183	102	32	59	258	272	168	49
WEIGHTED	1840	206	66	120	518	273	338	100

NODE NO. 53 TOTAL LINKS 3
X,Y,Z COORDINATE 144. 76. 300

LINKED TO	63	-48	-57
EXPOSURE	61	100	186
WEIGHTED	62	101	187

NODE NO. 63 TOTAL LINKS 4
X,Y,Z COORDINATE 150. 91. 360

LINKED TO	73	-57	-61	-58
EXPOSURE	26	242	157	170
WEIGHTED	27	243	316	342

NODE NO. 73 TOTAL LINKS 6
X,Y,Z COORDINATE 150. 105. 360

LINKED TO	82	-65	-61	-67	-58	-57
EXPOSURE	35	348	181	262	171	151
WEIGHTED	36	658	182	2630	172	152

NODE NO. 82 TOTAL LINKS 5
X,Y,Z COORDINATE 149. 115. 340

LINKED TO	93	-77	-69	-76	-67
EXPOSURE	64	211	314	165	242
WEIGHTED	65	212	315	166	243

NODE NO. 93 TOTAL LINKS 4
X,Y,Z COORDINATE 147. 132. 330

LINKED TO	103	-77	-92	-76
EXPOSURE	31	280	160	183
WEIGHTED	64	562	161	1840

NODE NO. 103 TOTAL LINKS 6
X,Y,Z COORDINATE 146. 146. 320

LINKED TO	90	83	-92	-87	-77	-76
EXPOSURE	115	55	176	246	224	215
WEIGHTED	1160	560	177	494	225	2160

NODE NO. -92 TOTAL LINKS 7
X,Y,Z COORDINATE 140. 143. 330

LINKED TO	90	63	88	-87	-77	-76	-93
EXPOSURE	143	100	164	295	250	238	179
WEIGHTED	1440	1010	.650	592	251	2390	180

NODE NO. -93 TOTAL LINKS 4
X,Y,Z COORDINATE 115. 144. 330

LINKED TO	90	-85	-87	-81
EXPOSURE	125	253	324	162
WEIGHTED	1260	254	650	326

NODE NO. -85 TOTAL LINKS 3
X,Y,Z COORDINATE 104. 137. 330

LINKED TO	88	92	-81
EXPOSURE	296	156	358
WEIGHTED	2970	157	3590

NODE NO. 92 TOTAL LINKS 9
X,Y,Z COORDINATE 91. 129. 300

LINKED TO	91	86	99	80	-81	-78	-90	-75
EXPOSURE	253	281	96	208	315	255	196	239
WEIGHTED	762	282	48500	62700	158000	25600	59700	24000

Case 4 - Area 1, Route 2, Sensor Set 2.

Table A.5. Case 4 - Node Linkage for Route

FROM	EASTING	NORTHING	TO	PENALTY	EASTING	NORTHING
31	770	10150	35	164	1470	10500
35	1470	10500	-24	165	2450	9590
-24	2450	9590	-22	177	3290	9240
-22	3290	9240	32	145	2590	10290
32	2590	10290	30	220	1610	10010
30	1610	10010	28	230	560	9800
28	560	9800	34	185	770	10430
34	770	10430	45	34	70	11480
45	70	11480	55	205	560	12390
55	560	12390	-33	153	2660	10920
-33	2660	10920	51	337	2660	11760
51	2660	11760	57	198	2940	12670
57	2940	12670	67	192	3850	13650
67	3850	13650	76	334	3920	14420
76	3920	14420	-73	302	4550	15120
-73	4550	15120	-78	261	5390	15890
-78	5390	15890	-90	281	5390	16660
-90	5390	16660	89	320	6370	16030
89	6370	16030	99	270	5810	17010
99	5810	17010	91	604	6020	16030
91	6020	16030	94	566	5250	16450
94	5250	16450	104	128	4760	17290
104	4760	17290	102	2	3710	17220
102	3710	17220	100	2	2660	17080
100	2660	17080	93	14	1610	16450
93	1610	16450	84	2	1120	15400
84	1120	15400	85	101	1120	15540
85	1120	15540	97	32	580	16590
97	980	16590	86	202	770	15890
86	770	15690	98	1	1750	16870
98	1750	16870	81	46	490	15190
81	490	15190	95	29	2240	16450
95	2240	16450	-86	177	3080	16590
-86	3080	16590	-88	296	3430	16590
-88	3430	16590	-89	167	4480	16660
-89	4480	16660	87	340	3990	15960
87	3990	15960	-65	290	4270	14350
-65	4270	14350	-56	408	3290	13300
-56	3290	13300	-63	274	3290	14280
-63	3290	14280	-74	274	3430	15120
-74	3430	15120	-82	309	3360	16030
-82	3360	16030	-59	462	1540	13930
-59	1540	13930	-71	284	1750	14910
-71	1750	14910	-53	240	2310	13160
-53	2310	13160	-43	302	2240	12180
-43	2240	12180	46	374	1750	11480
46	1750	11480	56	200	2100	12390
56	2100	12390	64	234	2100	13370
64	2100	13370	75	215	3150	14420
75	3150	14420	-72	490	2450	15050
-72	2450	15050	65	2[illegible]	3080	13510
65	3080	13510	-64	494	2240	14280
-64	2240	14280	-83	274	2870	16100
-83	2870	16100	101	98	6720	17150
101	6720	17150	-93	307	8050	17080
-93	8050	17080	-87	325	8890	16590
-87	8890	16590	96	340	9450	16450

Table A.6. Case 4 - Node Linkage

```
NODE NO.   31 TOTAL LINKS     7
X,Y,Z COORDINATE   11,   45,  280
LINKED TO       34     28     35     30    -21    -23    -36
EXPOSURE       201    158     81    119    139    180    203
WEIGHTED       202    318    164    240    280    181    204

NODE NO.   35 TOTAL LINKS     8
X,Y,Z COORDINATE   21,   50,  280
LINKED TO       30     34     46     28    -34    -38    -23    -24
EXPOSURE       193    178    237     98    282    238    207    164
WEIGHTED       388    358    238    199    283    478    416    165

NODE NO.  -24 TOTAL LINKS     7
X,Y,Z COORDINATE   35,   37,  290
LINKED TO       29     32     18     30     15    -22    -23
EXPOSURE       243    195    178    103    201    176    203
WEIGHTED       486    196    356    208    404    177    406

NODE NO.  -22 TOTAL LINKS     6
X,Y,Z COORDINATE   47,   32,  290
LINKED TO       18     24     20     25     32    -14
EXPOSURE       253    211    171    190    144    235
WEIGHTED       508    424    172    191    145    472

NODE NO.   32 TOTAL LINKS     5
X,Y,Z COORDINATE   37,   47,  280
LINKED TO       25     30    -33    -34    -36
EXPOSURE       243    109    314    249    266
WEIGHTED       488    220    315    500    534

NODE NO.   30 TOTAL LINKS     6
X,Y,Z COORDINATE   23,   43,  280
LINKED TO       34     28    -23    -34    -21    -33
EXPOSURE       157    114    303    275    167    248
WEIGHTED       316    230    606    276    336    498

NODE NO.   28 TOTAL LINKS     3
X,Y,Z COORDINATE    8,   40,  280
LINKED TO       34    -21    -23
EXPOSURE       184    236    203
WEIGHTED       185    474    204

NODE NO.   34 TOTAL LINKS     3
X,Y,Z COORDINATE   11,   49,  280
LINKED TO       45    -38    -23
EXPOSURE        33    297    119
WEIGHTED        34    298    120

NODE NO.   45 TOTAL LINKS     3
X,Y,Z COORDINATE    1,   64,  300
LINKED TO       55    -38    -42
EXPOSURE       204    206    255
WEIGHTED       205    207    256

NODE NO.   55 TOTAL LINKS    16
X,Y,Z COORDINATE    8,   77,  340
LINKED TO       70     46     56     64     51    -42    -44    -52    -54    -38
LINKED TO      -43    -55    -53    -34    -64    -33
EXPOSURE       254    192    213    240    176    265    268    290    291    187
EXPOSURE       209    263    242    163    247    152
WEIGHTED       255    183    428    241    354    532    538    291    292    376
WEIGHTED       420    264    486    164    248    153

NODE NO.  -33 TOTAL LINKS     6
X,Y,Z COORDINATE   38,   56,  300
LINKED TO       51     29     46    -36    -34    -40
EXPOSURE       336    201    274    366    323    277
WEIGHTED       337    404    550    367    648    556

NODE NO.   51 TOTAL LINKS     7
X,Y,Z COORDINATE   38,   48,  300
LINKED TO       56     46     57    -43    -40    -36    -34
EXPOSURE       288    162    197    341    216    201    134
 EIGHTED       578    326    198    664    434    202    270
```

Table A.6. (cont'd.)

NODE NO. 57 TOTAL LINKS 9
X,Y,Z COORDINATE 42, 81, 300

LINKED TO	59	65	56	64	67	-56	-53	-43	-40
EXPOSURE	279	284	253	284	191	310	338	261	237
WEIGHTED	560	285	508	570	192	311	676	524	238

NODE NO. 67 TOTAL LINKS 9
X,Y,Z COORDINATE 55, 95, 300

LINKED TO	76	65	59	68	75	58	-56	-65	-63
EXPOSURE	333	284	256	257	300	213	310	334	339
WEIGHTED	334	570	514	516	602	428	622	335	680

NODE NO. 76 TOTAL LINKS 7
X,Y,Z COORDINATE 56, 106, 320

LINKED TO	75	68	65	-65	-63	-74	-73
EXPOSURE	296	229	197	345	314	310	301
WEIGHTED	594	2290	396	692	630	622	302

NODE NO. -73 TOTAL LINKS 6
X,Y,Z COORDINATE 65, 116, 330

LINKED TO	77	87	-65	-75	-80	-78
EXPOSURE	306	307	361	362	369	260
WEIGHTED	3070	616	724	726	370	261

NODE NO. -78 TOTAL LINKS 7
X,Y,Z COORDINATE 77, 127, 320

LINKED TO	94	91	89	-75	-80	-90	-89
EXPOSURE	314	290	192	363	355	280	262
WEIGHTED	630	582	386	728	720	281	526

NODE NO. -80 TOTAL LINKS 4
X,Y,Z COORDINATE 77, 138, 310

LINKED TO	91	89	-89	-80
EXPOSURE	301	159	355	343
WEIGHTED	604	320	712	688

NODE NO. 89 TOTAL LINKS 6
X,Y,Z COORDINATE 91, 129, 300

LINKED TO	91	99	90	-81	-85	-75
EXPOSURE	301	134	209	363	288	293
WEIGHTED	604	270	2100	3640	289	588

NODE NO. 99 TOTAL LINKS 2
X,Y,Z COORDINATE 93, 143, 300

LINKED TO	91	-85
EXPOSURE	301	454
WEIGHTED	604	4950

NODE NO. 91 TOTAL LINKS 2
X,Y,Z COORDINATE 86, 129, 300

LINKED TO	94	-75
EXPOSURE	282	298
WEIGHTED	566	598

NODE NO. 94 TOTAL LINKS 3
X,Y,Z COORDINATE 75, 135, 310

LINKED TO	104	-80	-89
EXPOSURE	63	379	335
WEIGHTED	128	760	660

NODE NO. 104 TOTAL LINKS 2
X,Y,Z COORDINATE 68, 147, 300

LINKED TO	102	-89
EXPOSURE	0	362
WEIGHTED	2	726

NODE NO. 102 TOTAL LINKS 4
X,Y,Z COORDINATE 53, 146, 300

LINKED TO	100	-88	-86	-89
EXPOSURE	0	345	195	268
WEIGHTED	2	692	392	536

Table A.6.(cont'd.)

```
NODE NO.  100 TOTAL LINKS     7
X,Y,Z COORDINATE    38,  144,  300
LINKED TO        95      98      93     -86     -88     -83     -82
EXPOSURE        101      53       6     230     283     284     253
WEIGHTED        204     108      14     462     568     285     508

NODE NO.   93 TOTAL LINKS     8
X,Y,Z COORDINATE    23,  135,  300
LINKED TO        98      95      97      86      85      84     -75     -94
EXPOSURE        100      53      71      20      17       0     297     133
WEIGHTED        101     108     144      42      36       2     298     268

NODE NO.   84 TOTAL LINKS     7
X,Y,Z COORDINATE    16,  120,  300
LINKED TO        85      86      81     -71     -75     -68     -84
EXPOSURE        100      58      52     233     216     186     177
WEIGHTED        101     116     106     466     217     374     356

NODE NO.   85 TOTAL LINKS     7
X,Y,Z COORDINATE    16,  122,  300
LINKED TO        86      81      97     -79     -71     -68     -84
EXPOSURE        100      66      15     234     233     168     177
WEIGHTED        202     134      32     235     466     338     356

NODE NO.   97 TOTAL LINKS     3
X,Y,Z COORDINATE    14,  137,  300
LINKED TO        86     -84     -79
EXPOSURE        100     227     186
WEIGHTED        202     456     374

NODE NO.   86 TOTAL LINKS     4
X,Y,Z COORDINATE    11,  127,  300
LINKED TO        81      98     -84     -71
EXPOSURE         90       0     277     193
WEIGHTED        182       1     556     388

NODE NO.   98 TOTAL LINKS    11
X,Y,Z COORDINATE    25,  141,  300
LINKED TO        81     -75     -83     -86     -91     -88     -84     -82     -72     -71
LINKED TO       -74
EXPOSURE         22     286     280     175     230     247     224     268     242     225
EXPOSURE        219
WEIGHTED         46     287     562     352     462     496     450     522     243     226
WEIGHTED        440

NODE NO.   81 TOTAL LINKS    14
X,Y,Z COORDINATE     7,  117,  300
LINKED TO        70      55      64     -68     -84     -71     -79     -59     -91     -72
LINKED TO       -64     -54     -52     -53
EXPOSURE        232      28     191     261     261     259     238     242     213     241
EXPOSURE        242     213     195     182
WEIGHTED        466      29     192     262     524     520     235     243     428     484
WEIGHTED        486     214     392     183

NODE NO.   95 TOTAL LINKS    15
X,Y,Z COORDINATE    32,  135,  310
LINKED TO        87      75     -75     -83     -86     -82     -88     -94     -72     -71
LINKED TO       -74     -51     -84     -68     -65
EXPOSURE        235     217     273     290     176     281     257     133     263     238
EXPOSURE        252     205     212     171     197
WEIGHTED        472     218     548     582     177     564     258     268     264     478
WEIGHTED        506     412     426     344     396

NODE NO.  -86 TOTAL LINKS     4
X,Y,Z COORDINATE    44,  137,  340
LINKED TO        87     -88     -83     -82
EXPOSURE        169     295     315     314
WEIGHTED        340     296     632     630

NODE NO.  -88 TOTAL LINKS     4
X,Y,Z COORDINATE    49,  137,  340
LINKED TO        87     -82     -83     -89
EXPOSURE        212     351     302     166
WEIGHTED        426     704     606     167

NODE NO.  -89 TOTAL LINKS     2
X,Y,Z COORDINATE    64,  136,  330
LINKED TO        87     -88
EXPOSURE        169     283
WEIGHTED        340     568
```

Table A.6. (cont'd.)

```
NODE NO.   87 TOTAL LINKS   14
X,Y,Z COORDINATE    57,  128,  330
LINKED TO        75     77     78     71    -82    -80    -74    -83    -75    -65
LINKED TO       -72    -63    -79    -64
EXPOSURE        276    257    247    234    353    338    330    319    303    289
EXPOSURE        291    277    254    262
WEIGHTED        554   2520    496   2350    708    678    662    640    609    290
WEIGHTED        584    556    510    526

NODE NO.  -65 TOTAL LINKS    5
X,Y,Z COORDINATE    61,  135,  320
LINKED TO        68     77    -63    -74    -56
EXPOSURE        314    304    318    313    203
WEIGHTED       3150    610    638    628    408

NODE NO.  -56 TOTAL LINKS    5
X,Y,Z COORDINATE    47,   90,  310
LINKED TO        65     59    -63    -53    -64
EXPOSURE        292    258    273    252    246
WEIGHTED        586    518    274    506    494

NODE NO.  -63 TOTAL LINKS    5
X,Y,Z COORDINATE    47,  104,  330
LINKED TO        75     65    -74    -64    -72
EXPOSURE        318    299    273    255    244
WEIGHTED        638    420    274    512    490

NODE NO.  -74 TOTAL LINKS    4
X,Y,Z COORDINATE    45,  116,  340
LINKED TO        75    -62    -72    -83
EXPOSURE        269    308    281    239
WEIGHTED        540    309    564    480

NODE NO.  -82 TOTAL LINKS   10
X,Y,Z COORDINATE    48,  129,  350
LINKED TO        75     77    -83    -80    -72    -79    -71    -64    -75    -59
EXPOSURE        275    233    342    305    308    279    265    277    273    230
WEIGHTED        560   2340    686    612    616    560    532    556    546    462

NODE NO.  -59 TOTAL LINKS    8
X,Y,Z COORDINATE    22,   99,  350
LINKED TO        64     70    -54    -64    -71    -68    -53    -52
EXPOSURE        246    262    322    343    203    244    193    203
WEIGHTED        494    526    642    344    284    490    388    408

NODE NO.  -71 TOTAL LINKS   15
X,Y,Z COORDINATE    25,  113,  350
LINKED TO        75     64     70     65     55    -72    -64    -79    -68    -83
LINKED TO       -54    -53    -64    -52    -91
EXPOSURE        271    245    228    226    185    309    336    273    245    263
EXPOSURE        237    239    216    202    181
WEIGHTED        544    246    458    458    386    620    614    274    452    264
WEIGHTED        476    240    434    406    364

NODE NO.  -53 TOTAL LINKS    4
X,Y,Z COORDINATE    33,   85,  330
LINKED TO        64     56     65    -43
EXPOSURE        343    174    192    150
WEIGHTED        408    350    386    302

NODE NO.  -43 TOTAL LINKS    4
X,Y,Z COORDINATE    32,   74,  310
LINKED TO        55     46    -44    -54
EXPOSURE        267    186    217    222
WEIGHTED        536    374    436    446

NODE NO.   44 TOTAL LINKS    4
X,Y,Z COORDINATE    25,   64,  300
LINKED TO        56    -34    -44    -38
EXPOSURE        199    234    253    138
WEIGHTED        200    470    508    276

NODE NO.   56 TOTAL LINKS    3
X,Y,Z COORDINATE    30,   77,  310
LINKED TO        64    -44    -54
EXPOSURE        233    223    220
WEIGHTED        234    448    442
```

Table A.6. (cont'd.)

```
NODE NO.   64 TOTAL LINKS     4
X,Y,Z COORDINATE   30,   91,  330
LINKED TO        65      75     -54     -64
EXPOSURE        260     218     322     345
WEIGHTED        522     219     646     345

NODE NO.   75 TOTAL LINKS     3
X,Y,Z COORDINATE   45,  106,  330
LINKED TO        65     -64     -72
EXPOSURE        273     318     244
WEIGHTED        548     638     492

NODE NO.  -72 TOTAL LINKS     8
X,Y,Z COORDINATE   35,  115,  350
LINKED TO        65      75     -64     -79     -83     -68     -54     -52
EXPOSURE        228     229     345     311     324     245     248     205
WEIGHTED        229     460     692     624     325     492     498     412

NODE NO.   65 TOTAL LINKS     2
X,Y,Z COORDINATE   44,   93,  310
LINKED TO        59     -64
EXPOSURE        289     246
WEIGHTED        580     494

NODE NO.  -64 TOTAL LINKS     9
X,Y,Z COORDINATE   37,  104,  350
LINKED TO        70      59     -54     -68     -79     -83     -52     -44     -84
EXPOSURE        250     244     286     257     274     273     227     196     177
WEIGHTED        502     490     574     516     275     274     456     394     356

NODE NO.  -83 TOTAL LINKS    28
X,Y,Z COORDINATE   41,  130,  350
LINKED TO        77      68      70      76      59      71      58     101      79      72
LINKED TO        60      62      52     -79     -80     -94     -75     -84     -68     -51
LINKED TO       -54     -52     -40     -44     -41     -42     -49     -39
EXPOSURE        273     266     216     269     233     271     248      97     204     201
EXPOSURE        184     183     167     286     301     157     293     237     226     227
EXPOSURE        232     204     206     184     226     158     188     167
WEIGHTED       2740    2670     434     540     234    2720     498      98    2050    2020
WEIGHTED       1650    1840    1680     574     604     316     588     476     454     456
WEIGHTED        466     410     207     370     454     318    1890    1680

NODE NO.  101 TOTAL LINKS     8
X,Y,Z COORDINATE   56,  145,  300
LINKED TO        88      90      83     -85     -81     -93     -75     -80
EXPOSURE        306     271     259     346     376     306     222     286
WEIGHTED       3070    2720    2600     694    3770     307     446     574

NODE NO.  -93 TOTAL LINKS     4
X,Y,Z COORDINATE  115,  144,  330
LINKED TO        90     -85     -87     -81
EXPOSURE        194     255     324     210
WEIGHTED       1550     512     325     422

NODE NO.  -87 TOTAL LINKS     6
X,Y,Z COORDINATE  127,  137,  340
LINKED TO        96      90      88     -92     -76     -77
EXPOSURE        339     252     182     171     230     289
WEIGHTED        340  126500   91500   17200   69300   21000
```

Case 5 - Area 2, Route 1, Sensor Set 1.

Table A.7. Case 5 - Node Linkage for Route

FROM	EASTING	NORTHING	TO	PENALTY	EASTING	NORTHING
3	3820	7280	9	1	4870	7630
9	4870	7630	13	1	4450	8470
13	4450	8470	7	50	5290	7630
7	5290	7630	-2	40	4240	7280
-2	4240	7280	11	202	4100	7980
11	4100	7980	31	17	2560	9870
31	2560	9870	37	2	3470	10640
37	3470	10640	32	37	4240	10080
32	4240	10080	36	52	5290	10640
36	5290	10640	35	160	4730	10430
35	4730	10430	46	54	5500	11270
46	5500	11270	38	105	6340	10710
38	6340	10710	33	36	5500	10150
33	5500	10150	-21	56	5010	9100
-21	5010	9100	12	34	5430	8190
12	5430	8190	22	38	5570	9170
22	5570	9170	28	93	3610	9660
28	3610	9660	19	60	4100	9100
19	4100	9100	-23	72	3120	9240
-23	3120	9240	23	3	4170	9240
23	4170	9240	42	34	2980	11060
42	2980	11060	34	64	2280	10360
34	2280	10360	56	56	2630	12320
56	2630	12320	50	29	3260	11550
50	3260	11550	57	118	3890	12390
57	3890	12390	-62	2	2840	13090
-62	2840	13090	70	166	2210	14000
70	2210	14000	82	88	2560	14910
82	2560	14910	-76	236	2910	14420
-76	2910	14420	-71	492	2700	13720
-71	2700	13720	-52	62	4660	11830
-52	4660	11830	45	92	5150	11270
45	5150	11270	65	10	7180	13230
65	7180	13230	71	20	8020	14140
71	8020	14140	79	65	8790	14560
79	8790	14560	81	190	9560	14770

Table A.8. Case 5 - Node Linkage

```
NODE NO.    3 TOTAL LINKS     5
X,Y,Z COORDINATE    25.     4.  350
LINKED TO        11      8      9     -2     -1
EXPOSURE         75    148      0    148    206
WEIGHTED        152    298      1    149    414

NODE NO.    9 TOTAL LINKS     5
X,Y,Z COORDINATE    41.     9.  290
LINKED TO         7     12     11     13     -2
EXPOSURE        147     75     65      0    137
WEIGHTED        148    152    132      1    276

NODE NO.   13 TOTAL LINKS     6
X,Y,Z COORDINATE    25.    21.  290
LINKED TO        11     19     23     12      7    -21
EXPOSURE        124     79     87     53     24    156
WEIGHTED        250     80     88     54     50    314

NODE NO.    7 TOTAL LINKS     4
X,Y,Z COORDINATE    47.     9.  300
LINKED TO        12    -10     -2    -12
EXPOSURE        100    234     19    218
WEIGHTED        202    235     40    219

NODE NO.   -2 TOTAL LINKS     2
X,Y,Z COORDINATE    32.     4.  310
LINKED TO        11     -1
EXPOSURE        100    176
WEIGHTED        202    274

NODE NO.   11 TOTAL LINKS    21
X,Y,Z COORDINATE    30.    14.  300
LINKED TO        19     23      8     12     18     28     22     32     31    -13
LINKED TO        -1    -21    -23    -26     -3    -18    -10    -12    -24    -20
LINKED TO       -27
EXPOSURE         91     98    185     92     95     64    103     39     16    149
EXPOSURE        195    134     91    278    209    217    238    240    145    243
EXPOSURE        244
WEIGHTED        184    198    372     93     96     65    208     80     17    300
WEIGHTED        292    278     92    558    428    436    235    241    292    244
WEIGHTED        490

NODE NO.   31 TOTAL LINKS     6
X,Y,Z COORDINATE     8.    41.  300
LINKED TO        34     18     28     37    -24    -23
EXPOSURE        100     64     19      0    225     80
WEIGHTED        101    130     20      2    452     81

NODE NO.   37 TOTAL LINKS     7
X,Y,Z COORDINATE    21.    52.  300
LINKED TO        42     50     37     28    -40    -41    -48
EXPOSURE        100     40     36     28    255    182     92
WEIGHTED        202     82     37     58    512    366    190

NODE NO.   32 TOTAL LINKS     9
X,Y,Z COORDINATE    32.    44.  300
LINKED TO        35     28     23     19     36    -26    -40    -41    -21
EXPOSURE        116     52     79     39     25    308    204    208     65
WEIGHTED        234    156    153     80     52    309    410    418    132

NODE NO.   36 TOTAL LINKS    12
X,Y,Z COORDINATE    47.    52.  300
LINKED TO        33     35     45     46     38     47    -32    -39    -41    -43
LINKED TO       -27    -26
EXPOSURE        159     89    160    118    181    166    272    281    285    180
EXPOSURE        256    231
WEIGHTED        318    180    322    238   1820   1670    273    484    412   1610
WEIGHTED        502    464

NODE NO.   35 TOTAL LINKS     7
X,Y,Z COORDINATE    39.    45.  300
LINKED TO        33     45     46    -41    -26    -40    -27
EXPOSURE        111    123     26    268    304    223    238
WEIGHTED        112    248     54    538    610    448    239

NODE NO.   46 TOTAL LINKS     9
X,Y,Z COORDINATE    50.    61.  320
LINKED TO        45     47     36    -43    -33    -39    -52    -41    -32
EXPOSURE        100    136    104    143    141    122    109    174    154
WEIGHTED        202   1370    105   1443   1420    123    220    350    310
```

Table A.8. (cont'd.)

```
NODE NO.   38 TOTAL LINKS    8
X,Y,Z COORDINATE   62.   53.  340
LINKED TO       47     33     27    -39    -32    -43    -37    -27
EXPOSURE       195     17    246    232    271    200    320    237
WEIGHTED       392     36    494    466    544    402    321    476

NODE NO.   33 TOTAL LINKS    8
X,Y,Z COORDINATE   50.   45.  330
LINKED TO       22    -27    -32    -26    -39    -21    -43    -41
EXPOSURE        49    337    291    287    186     27    145    167
WEIGHTED       100    676    292    576    374     56    300    336

NODE NO.  -21 TOTAL LINKS    6
X,Y,Z COORDINATE   43.   30.  330
LINKED TO       22     23     19     12    -26    -27
EXPOSURE       158     48     19     16    330    250
WEIGHTED       159     58     40     34    662    502

NODE NO.   12 TOTAL LINKS    4
X,Y,Z COORDINATE   49.   17.  300
LINKED TO       22    -12    -10    -20
EXPOSURE        18    315    308    227
WEIGHTED        38    316    305    456

NODE NO.   22 TOTAL LINKS   23
X,Y,Z COORDINATE   51.   31.  330
LINKED TO       27     15     23     19     28     45      2      4    -27    -20
LINKED TO      -26    -12    -32    -10    -35     -8    -15    -28    -37    -43
LINKED TO      -41    -40    -36
EXPOSURE       307    267     74     54     44    134     76     69    340    327
EXPOSURE       314    290    301    278    206    253    261    275    289    191
EXPOSURE       189    174    260
WEIGHTED       308    298    150    110     90    210    154    140    682    328
WEIGHTED       633    582    604    558    416    508    262    276   2900    384
WEIGHTED       190    175   2610

NODE NO.   28 TOTAL LINKS    4
X,Y,Z COORDINATE   23.   36.  300
LINKED TO       23     19     18    -23
EXPOSURE       125     59     95    195
WEIGHTED       126     60    192    392

NODE NO.   19 TOTAL LINKS    4
X,Y,Z COORDINATE   30.   30.  290
LINKED TO       23    -26    -23    -13
EXPOSURE       100    260     35     39
WEIGHTED       202    522     72     80

NODE NO.  -23 TOTAL LINKS    5
X,Y,Z COORDINATE   16.   32.  310
LINKED TO       18     23    -24    -13    -18
EXPOSURE       119      2    154     66    187
WEIGHTED       240      3    310    134    376

NODE NO.   23 TOTAL LINKS   22
X,Y,Z COORDINATE   31.   32.  300
LINKED TO       18      8     42     34     45     47    -26    -13    -27    -40
LINKED TO      -41    -24    -20    -18     -1    -32    -12    -10    -39     -5
LINKED TO      -42    -43
EXPOSURE        97    137     33     32    102    166    330    113    256    216
EXPOSURE       219    173    272    228    131    264    248    240    179    169
EXPOSURE       104    169
WEIGHTED       196    276     34     66    218   1670    662    228    297    434
WEIGHTED       440    348    273    458    264    530    249    241    360    380
WEIGHTED       210   1700

NODE NO.   42 TOTAL LINKS    7
X,Y,Z COORDINATE   14.   58.  300
LINKED TO       50     52     34    -42    -45    -40    -48
EXPOSURE       130     73     31    153    132    188     56
WEIGHTED       202     74     64    308    266    378    158

NODE NO.   34 TOTAL LINKS   12
X,Y,Z COORDINATE    4.   48.  300
LINKED TO       52     18     50     56     57    -42    -45    -24    -18    -40
LINKED TO      -48    -13
EXPOSURE        61     79     58     33     56    198    182    207    236    205
EXPOSURE       122     62
WEIGHTED       124    160    118     68    118    199    183    416    478    412
WEIGHTED       246    126

NODE NO.   56 TOTAL LINKS    5
X,Y,Z COORDINATE    5.   76.  300
LINKED TO       57     50    -62    -45    -59
EXPOSURE       188     28    160    114     98
WEIGHTED       202     29    322    230    198
```

Table A.8. (cont'd.)

```
NODE NO.   50 TOTAL LINKS    4
X,Y,Z COORDINATE   18,   65,  300
LINKED TO       52      57     -48     -40
EXPOSURE       100      58     151     192
WEIGHTED       202     118     304     193

NODE NO.   57 TOTAL LINKS    6
X,Y,Z COORDINATE   27,   77,  330
LINKED TO       60     -59     -48     -52     -64     -62
EXPOSURE       101     100      75      48     205       0
WEIGHTED       204     202     152      49    2100       2

NODE NO.  -62 TOTAL LINKS    3
X,Y,Z COORDINATE   12,   87,  350
LINKED TO       70     -71     -59
EXPOSURE        82     279     165
WEIGHTED       166     280     332

NODE NO.   70 TOTAL LINKS    3
X,Y,Z COORDINATE    3,  100,  330
LINKED TO       82     -71     -76
EXPOSURE        87     279     175
WEIGHTED        88     560    1760

NODE NO.   82 TOTAL LINKS    6
X,Y,Z COORDINATE    8,  113,  330
LINKED TO       95      84      96     -76     -78     -74
EXPOSURE       142     145      90     237     192     219
WEIGHTED       286    1460     910     238    1930    2200

NODE NO.  -76 TOTAL LINKS    4
X,Y,Z COORDINATE   13,  106,  340
LINKED TO       84     -78     -74     -71
EXPOSURE        96     242     279     245
WEIGHTED       970    2430    2800     492

NODE NO.  -71 TOTAL LINKS   13
X,Y,Z COORDINATE   10,   96,  350
LINKED TO       75      84      52      72      60     -74     -78     -59     -64     -67
LINKED TO      -79     -48     -52
EXPOSURE       199     200      43     167     102     253     231     149     223     305
EXPOSURE       152      75      61
WEIGHTED      2000    2010      88    1680    1030    2540    2320     150     446    3060
WEIGHTED      1530      76      62

NODE NO.  -52 TOTAL LINKS    6
X,Y,Z COORDINATE   38,   69,  350
LINKED TO       45      60      59     -48     -41     -40
EXPOSURE        81     154     177     147     188     138
WEIGHTED        82     310    1780     296     378     278

NODE NO.   45 TOTAL LINKS   20
X,Y,Z COORDINATE   45,   61,  340
LINKED TO       47      59      60      27      65     -41     -53     -43     -40     -39
LINKED TO      -48     -32     -26     -27     -54     -37     -60     -64     -61     -59
EXPOSURE       188     213     122     211       4     211     125     191     188     183
EXPOSURE       118     242     224     233     311     250     321     225     311      65
WEIGHTED      1890    2140     246     212      10     424    1300    1920     378     184
WEIGHTED       238     243     450     468    3120     251    3220     452    3120     132

NODE NO.   65 TOTAL LINKS    9
X,Y,Z COORDINATE   74,   85,  330
LINKED TO       64      73      71      55     -66     -61     -56     -68     -54
EXPOSURE        53      47      19      37     137     344     211     325     297
WEIGHTED        54      48      20     380     138     690    2120     652    2980

NODE NO.   71 TOTAL LINKS    6
X,Y,Z COORDINATE   86,  102,  300
LINKED TO       80      73      75      64     -65     -66
EXPOSURE       100      67      85      32      91      96
WEIGHTED       101     136      86     330      92     970

NODE NO.   79 TOTAL LINKS   10
X,Y,Z COORDINATE   57,  108,  300
LINKED TO       81      67      77      80      85      53      66     -82     -69     -81
EXPOSURE       189      74     140      91     345     276       0     300      94     243
WEIGHTED       190   22500   14100   64400  103800   27700     300     903   47500  122000
```

Case 6 - Area 2, Route 2, Sensor Set 1.

Table A.9. Case 6 - Node Linkage for Route

FROM	EASTING	NORTHING	TO	PENALTY	EASTING	NORTHING
35	2770	10500	28	1	3610	9660
28	3610	9660	19	77	4100	9100
19	4100	9100	31	66	4240	10080
31	4240	10080	36	18	5290	10640
36	5290	10640	34	180	4730	10430
34	4730	10430	46	54	5500	11270
46	5500	11270	38	105	6340	10710
38	6340	10710	32	38	5500	10150
32	5500	10150	-21	56	5010	9100
-21	5010	9100	11	34	5430	8190
11	5430	8190	12	10	4450	8470
12	4450	8470	22	96	4170	9240
22	4170	9240	42	51	2980	11060
42	2980	11060	33	64	2280	10360
33	2280	10360	-45	59	2070	11410
-45	2070	11410	56	2	2630	12320
56	2630	12320	50	29	3260	11550
50	3260	11550	37	46	3470	10640
37	3470	10640	30	2	2560	9870
30	2560	9870	15	2	2580	9030
15	2580	9030	9	7	4870	7630
9	4870	7630	10	2	4100	7980
10	4100	7980	-23	57	3120	9240
-23	3120	9240	-2	62	4240	7280
-2	4240	7280	7	1	5290	7630
7	5290	7630	-13	36	3190	8400
-13	3190	8400	-24	216	2280	9240
-24	2280	9240	-1	118	3190	7280
-1	3190	7280	8	252	2840	7630
8	2840	7630	52	44	2770	11760
52	2770	11760	57	156	3890	12390
57	3890	12390	-62	2	2840	13090
-62	2840	13090	70	166	2210	14000
70	2210	14000	81	68	2560	14510
81	2560	14510	-76	238	2910	14420
-76	2910	14420	-71	492	2700	13720
-71	2700	13720	-52	40	4660	11830
-52	4660	11830	45	82	5150	11270
45	5150	11270	65	10	7180	13230
65	7180	13230	71	20	8020	14140
71	8020	14140	79	86	6790	14560
79	6790	14560	66	1	9840	13510
66	9840	13510	61	68	10260	12670
61	10260	12670	67	1	9280	13720
67	9280	13720	-58	2	9840	12880
-58	9840	12880	69	91	10890	13860
69	10890	13860	62	2	10680	12810
62	10680	12610	68	56	11590	13860
68	11590	13860	76	41	10610	14420
76	10610	14420	84	246	10960	14980

Table A.10. Case 6 - Node Linkage

```
NODE NO.   35 TOTAL LINKS     8
X,Y,Z COORDINATE   11,   50,  300
LINKED TO        33      42      30      37      50      28     -42     -45
EXPOSURE        100      86      77      69       4       0     141     103
WEIGHTED        202     174     156     140      10       1     284     208

NODE NO.   28 TOTAL LINKS     7
X,Y,Z COORDINATE   23,   38,  300
LINKED TO        22      19      31      15      37      30     -23
EXPOSURE        134      76     121     137      66      47     195
WEIGHTED        135      77     244     276     134      96     392

NODE NO.   19 TOTAL LINKS     7
X,Y,Z COORDINATE   30,   30,  290
LINKED TO        22      12      31     -26     -21     -23     -13
EXPOSURE        116      43      32     260      89      48      49
WEIGHTED        234      86      66     522      90      98     100

NODE NO.   31 TOTAL LINKS     8
X,Y,Z COORDINATE   32,   44,  300
LINKED TO        34      22      37      35     -26     -40     -41     -21
EXPOSURE        100      62      45       8     308     204     207      58
WEIGHTED        202     126      92      18     305     410     416      59

NODE NO.   36 TOTAL LINKS    12
X,Y,Z COORDINATE   47,   52,  300
LINKED TO        32      34      45      46      38      47     -32     -39     -41     -43
LINKED TO       -27     -26
EXPOSURE        158      89     160     118     181     166     272     201     205     180
EXPOSURE        250     231
WEIGHTED        318     180     322     238    1820    1670     273     404     412    1810
WEIGHTED        502     464

NODE NO.   34 TOTAL LINKS     7
X,Y,Z COORDINATE   35,   49,  300
LINKED TO        32      45      46     -41     -26     -40     -27
EXPOSURE        111     123      26     268     304     223     238
WEIGHTED        112     248      54     538     610     448     235

NODE NO.   46 TOTAL LINKS     9
X,Y,Z COORDINATE   50,   51,  320
LINKED TO        45      47      33     -43     -53     -39     -52     -41     -32
EXPOSURE        100     136     104     143     141     122     109     174     154
WEIGHTED        202    1370     105    1440    1420     123     220     350     310

NODE NO.   36 TOTAL LINKS     8
X,Y,Z COORDINATE   62,   53,  340
LINKED TO        47      32      27     -39     -32     -43     -37     -27
EXPOSURE        195      17     246     232     271     200     320     237
WEIGHTED        392      36     494     465     544     402     321     476

NODE NO.   32 TOTAL LINKS     8
X,Y,Z COORDINATE   55,   45,  330
LINKED TO        21     -27     -32     -26     -35     -21     -43     -41
EXPOSURE         49     327     291     287     195      27     149     167
WEIGHTED        100     676     292     576     374      56     300     336

NODE NO.  -21 TOTAL LINKS     6
X,Y,Z COORDINATE   43,   30,  330
LINKED TO        21      12      22      11     -26     -27
EXPOSURE        158      33      46      16     330     250
WEIGHTED        159      66      98      34     662     502

NODE NO.   11 TOTAL LINKS     7
X,Y,Z COORDINATE   49,   17,  300
LINKED TO         7       5      21      12     -12     -10     -20
EXPOSURE        116      53      76       4     276     270     230
WEIGHTED        234     106     154      10     277     271     462

NODE NO.   12 TOTAL LINKS     5
X,Y,Z COORDINATE   35,   21,  290
LINKED TO        10      22       9       7     -10
EXPOSURE        116      57      70      65     366
WEIGHTED        234      98     142     132     367
```

Table A.10. (cont'd.)

```
NODE NO.   22 TOTAL LINKS    30
X,Y,Z COORDINATE    31.    32.  300
LINKED TO        15      10      21      37      30       9       7       8      42      33
LINKED TO        45      47     -26     -23     -13     -27     -40     -41     -24      -2
LINKED TO       -20     -18      -1     -32     -12     -10     -35      -3     -42     -43
EXPOSURE        110      91     134      78      70      52      60     144      50      49
EXPOSURE        112     149     330     117     123     297     216     219     176      76
EXPOSURE        273     228     138     267     248     240     183     189     105     173
WEIGHTED        222     164     135      79     142     106     122     290      51     100
WEIGHTED        226    1700     662     236     248     296     434     440     354     154
WEIGHTED        274     458     278     536     249     241     366     380     212    1740

NODE NO.   42 TOTAL LINKS     8
X,Y,Z COORDINATE    14.    58.  300
LINKED TO        50      37      52      33     -42     -45     -40     -48
EXPOSURE        100      67      73      31     153     132     188      98
WEIGHTED        202      68      74      64     308     266     376     198

NODE NO.   33 TOTAL LINKS     3
X,Y,Z COORDINATE     4.    49.  300
LINKED TO        30     -42     -45
EXPOSURE        100     154      96
WEIGHTED        101     155      99

NODE NO.  -45 TOTAL LINKS     3
X,Y,Z COORDINATE     1.    63.  350
LINKED TO        52      56     -42
EXPOSURE         36       0     194
WEIGHTED         74       2     396

NODE NO.   56 TOTAL LINKS     4
X,Y,Z COORDINATE     5.    76.  300
LINKED TO        52      50     -62     -59
EXPOSURE        100      28     160      98
WEIGHTED        202      29     322     199

NODE NO.   50 TOTAL LINKS     5
X,Y,Z COORDINATE    18.    65.  300
LINKED TO        52      37      57     -48     -40
EXPOSURE        100      22      58     151     192
WEIGHTED        202      46     118     304     193

NODE NO.   37 TOTAL LINKS     4
X,Y,Z COORDINATE    21.    52.  300
LINKED TO        30     -40     -41     -48
EXPOSURE          0     266     195     110
WEIGHTED          2     534     392     222

NODE NO.   30 TOTAL LINKS     3
X,Y,Z COORDINATE     8.    41.  300
LINKED TO        15     -24     -23
EXPOSURE          0     244      38
WEIGHTED          2     490      39

NODE NO.   15 TOTAL LINKS    14
X,Y,Z COORDINATE    14.    29.  310
LINKED TO         8      10       9     -23     -13     -24     -16      -3      -1     -26
LINKED TO        -2     -42     -40     -41
EXPOSURE        155      59       6     132     130     208     261     212     138     257
EXPOSURE         48     109     176     173
WEIGHTED        312      60       7     266     262     418     524     426     278     258
WEIGHTED         98     110     354     342

NODE NO.    9 TOTAL LINKS     3
X,Y,Z COORDINATE    41.     9.  290
LINKED TO         7      10      -2
EXPOSURE        100       0     120
WEIGHTED        101       2     242

NODE NO.   10 TOTAL LINKS    15
X,Y,Z COORDINATE    30.    14.  300
LINKED TO         7       8      21      -2     -13      -1     -23     -26      -3     -18
LINKED TO       -16     -12     -24     -20     -27
EXPOSURE         68     169      87     119     121     172      66     267     200     209
EXPOSURE        231     233     135     237     235
WEIGHTED         69     320     176     240     244     346      67     536     402     420
WEIGHTED        232     234     272     238     480

NODE NO.  -23 TOTAL LINKS    12
X,Y,Z COORDINATE    16.    32.  310
LINKED TO         6      45     -24     -13     -18     -26      -3      -1     -40     -42
LINKED TO       -41      -2
EXPOSURE        150      73     220     124     276     287     221     133     207     134
EXPOSURE        199      30
WEIGHTED        302     148     442     250     554     288     444     268     416     135
WEIGHTED        400      62
```

Table A.10. (cont'd.)

```
NODE NO.   -2 TOTAL LINKS    2
X,Y,Z COORDINATE   32,    4,  310
LINKED TO          7     -1
EXPOSURE           0    236
WEIGHTED           1    474

NODE NO.    7 TOTAL LINKS   13
X,Y,Z COORDINATE   47,    9,  300
LINKED TO         21      2     13      3     27    -10    -12     -8    -20    -26
LINKED TO        -27     -1    -13
EXPOSURE          94     88    273     62    242    313    309    282    290    261
EXPOSURE         266     57     17
WEIGHTED         190     89    274     63    486    314    310    283    582    524
WEIGHTED         534    156     36

NODE NO.  -13 TOTAL LINKS    4
X,Y,Z COORDINATE   17,   20,  320
LINKED TO          8    -18    -24     -3
EXPOSURE         140    246    107    171
WEIGHTED         282    494    216    344

NODE NO.  -24 TOTAL LINKS    6
X,Y,Z COORDINATE    4,   32,  340
LINKED TO          8    -18     -3    -42     -1    -40
EXPOSURE          82    285    214    127     58    163
WEIGHTED         166    572    430    128    118    328

NODE NO.   -1 TOTAL LINKS    2
X,Y,Z COORDINATE   17,    4,  330
LINKED TO          8     -3
EXPOSURE         140    171
WEIGHTED         282    344

NODE NO.    8 TOTAL LINKS   23
X,Y,Z COORDINATE   12,    9,  330
LINKED TO         21 [illegible]  2   52     45     27     47     -3    -18    -26
LINKED TO        -10    -12    -20    -42    -27    -40    -41     -8    -48    -32
LINKED TO        -39    -43    -37
EXPOSURE         102    249     81     21     96    259    168    274    274    262
EXPOSURE         252    255    264    132    273    199    199    239    118    251
EXPOSURE         173    169    261
WEIGHTED         103    250     82     44    194    260   1690    550    275    566
WEIGHTED         253    256    265    133    548    400    400    240    238    504
WEIGHTED         348   1700   2620

NODE NO.   52 TOTAL LINKS   12
X,Y,Z COORDINATE   11,   68,  300
LINKED TO         57     60    -42    -48    -62    -40    -59    -41    -52    -71
LINKED TO        -64    -67
EXPOSURE          77     51    139    118    114    176    107    159     83    163
EXPOSURE         201    269
WEIGHTED         156    184    280    238    230    177    216    160    168   1640
WEIGHTED        2020   2700

NODE NO.   57 TOTAL LINKS    6
X,Y,Z COORDINATE   27,   77,  330
LINKED TO         60    -59    -48    -52    -64    -62
EXPOSURE         101    100     75     48    209      0
WEIGHTED         204    202    152     49   2100      2

NODE NO.  -62 TOTAL LINKS    3
X,Y,Z COORDINATE   12,   87,  350
LINKED TO         70    -71    -59
EXPOSURE          82    279    165
WEIGHTED         166    280    332

NODE NO.   70 TOTAL LINKS    3
X,Y,Z COORDINATE    3,  100,  330
LINKED TO         81    -71    -76
EXPOSURE          87    279    175
WEIGHTED          88    560   1760

NODE NO.   81 TOTAL LINKS    6
X,Y,Z COORDINATE    8,  113,  330
LINKED TO         95     82     96    -76    -78    -74
EXPOSURE         142    145     90    237    192    219
WEIGHTED         286   1460    910    238   1930   2200

NODE NO.  -76 TOTAL LINKS    4
X,Y,Z COORDINATE   13,  106,  340
LINKED TO         82    -78    -74    -71
EXPOSURE          96    242    279    245
WEIGHTED         970   2430   2800    492
```

Table A.10. (cont'd.)

```
NODE NO.  -71 TOTAL LINKS   12
X,Y,  COORDINATE    10,   96,  350
LINKED TO        75     82     72     80    -74    -78    -59    -64    -67    -79
LINKED TO       -48    -52
EXPOSURE        162    163    130     87    231    202    126    222    304    115
EXPOSURE         52     39
WEIGHTED       1630   1640   1310    880   2320   2030    127    446   3050   1160
WEIGHTED         53     40

NODE NO.  -52 TOTAL LINKS    6
X,Y,Z COORDINATE    38,   69,  350
LINKED TO        45     60     55    -48    -41    -40
EXPOSURE         81    154    177    147    188    138
WEIGHTED         82    310   1750    296    378    276

NODE NO.   45 TOTAL LINKS   21
X,Y,Z COORDINATE    45,   61,  340
LINKED TO        47     59     60     21     27     65    -41    -53    -43    -40
LINKED TO       -39    -48    -32    -26    -27    -54    -37    -60    -64    -61
LINKED TO       -59
EXPOSURE        188    213    122     32    211      0    211    129    191    188
EXPOSURE        183    118    242    224    233    311    250    321    225    311
EXPOSURE         65
WEIGHTED       1890   2140    246     66    212     10    424   1300   1920    378
WEIGHTED        184    238    243    450    468   3120    251   3220    452   3120
WEIGHTED        132

NODE NO.   65 TOTAL LINKS    9
X,Y,Z COORDINATE    74,   89,  330
LINKED TO        64     73     71     55    -66    -61    -56    -68    -54
EXPOSURE         53     47     19     37    137    344    211    325    297
WEIGHTED         54     48     20    380    138    690   2120    652   2980

NODE NO.   71 TOTAL LINKS    6
X,Y,Z COORDINATE    86,  102,  300
LINKED TO        80     73     79     64    -65    -66
EXPOSURE        100     67     85     32     91     96
WEIGHTED        202    136     86    330     92    970

NODE NO.   79 TOTAL LINKS    9
X,Y,Z COORDINATE    97,  108,  300
LINKED TO        67     77     80     89     53     66    -82    -69    -81
EXPOSURE         74    140     91    345    276      0    300     94    243
WEIGHTED         75    141    184    346    277      1    301    190    488

NODE NO.   66 TOTAL LINKS    9
X,Y,Z COORDINATE   112,   93,  250
LINKED TO        67     61     77     63     62     69     76    -72    -58
EXPOSURE         77     33    166    116    103    102    131    150    164
WEIGHTED        156     68    167    234    208    103    132    191    330

NODE NO.   61 TOTAL LINKS    6
X,Y,Z COORDINATE   118,   81,  290
LINKED TO        62     53     51     67    -58    -51
EXPOSURE        190    140     37      0    188     55
WEIGHTED        191    282     76      1    378    112

NODE NO.   67 TOTAL LINKS    5
X,Y,Z COORDINATE   104,   96,  290
LINKED TO        63     77    -72    -69    -58
EXPOSURE         41     76    100    132      0
WEIGHTED         84     77    101    266      2

NODE NO.  -58 TOTAL LINKS    6
X,Y,Z COORDINATE   112,   64,  300
LINKED TO        63     62     53     69    -72    -51
EXPOSURE        190    179    104     90    148     56
WEIGHTED        382    180    210     91    149    114

NODE NO.   69 TOTAL LINKS    7
X,Y,Z COORDINATE   127,   58,  300
LINKED TO        76     68     78     62    -65    -63    -72
EXPOSURE        140    114    158      0    331    195     15
WEIGHTED        141    115    159      2    664    392     40

NODE NO.   62 TOTAL LINKS    6
X,Y,Z COORDINATE   124,   83,  300
LINKED TO        58     55     68    -63    -65    -51
EXPOSURE        152     88     52    261    324     29
WEIGHTED        306    178     56    262    325     60
```

Table A.10. (cont'd.)

NODE NO. 68 TOTAL LINKS 5							
X,Y,Z COORDINATE 137. 98. 300							
LINKED TO	78	76	-65	-73	-63		
EXPOSURE	223	40	346	319	215		
WEIGHTED	224	41	694	640	432		

NODE NO. 76 TOTAL LINKS 7							
X,Y,Z COORDINATE 123. 106. 300							
LINKED TO	84	77	78	-72	-80	-84	-65
EXPOSURE	245	119	173	69	267	289	222
WEIGHTED	246	60000	52200	49000	28800	87000	111500

Case 7, Area 2, Route 1, Sensor Set 2.

Table A.11. Case 7 - Node Linkage for Route

FROM	EASTING	NORTHING	TO	PENALTY	EASTING	NORTHING
3	3820	7280	9	2	4870	7630
9	4870	7630	13	1	4450	8470
13	4450	8470	7	50	5290	7630
7	5290	7630	-2	40	4240	7280
-2	4240	7280	11	101	4100	7980
11	4100	7980	31	17	2560	9870
31	2560	9870	37	1	3470	10640
37	3470	10640	50	41	3260	11550
50	3260	11550	56	22	2630	12320
56	2630	12320	-59	159	3610	12950
-59	3610	12950	-71	80	2700	13720
-71	2700	13720	-78	48	3540	14560
-78	3540	14560	-79	1	4590	15120
-79	4590	15120	87	89	5150	15470
87	5150	15470	90	39	6060	15540
90	6060	15540	83	5	6900	14980
83	6900	14980	80	36	7810	14700
80	7810	14700	79	34	8790	14560
79	8790	14560	81	160	9560	14770

Table A.12. Case 7 - Node Linkage

```
NODE NO.    3 TOTAL LINKS     5
X,Y,Z COORDINATE   26,    4,  350
LINKED TO        11      8      9     -2     -1
EXPOSURE         75    107      0    148    166
WEIGHTED         76    216      2    298    334

NODE NO.    9 TOTAL LINKS     5
X,Y,Z COORDINATE   41,    9,  290
LINKED TO         7     12     11     13     -2
EXPOSURE        147     75     65      0    137
WEIGHTED        296    152    132      1    276

NODE NO.   13 TOTAL LINKS     6
X,Y,Z COORDINATE   35,   21,  290
LINKED TO        11     19     23     12      7    -21
EXPOSURE        124     79     87     53     24    156
WEIGHTED        250     80     88    108     50    314

NODE NO.    7 TOTAL LINKS     4
X,Y,Z COORDINATE   47,    9,  300
LINKED TO        12    -10     -2    -12
EXPOSURE        100    265     15    248
WEIGHTED        202    532     40    498

NODE NO.   -2 TOTAL LINKS     2
X,Y,Z COORDINATE   32,    4,  310
LINKED TO        11     -1
EXPOSURE        100     96
WEIGHTED        101    194

NODE NO.   11 TOTAL LINKS    21
X,Y,Z COORDINATE   30,   14,  300
LINKED TO        19     23      8     12     18     28     22     32     31    -13
LINKED TO        -1    -21    -23    -26     -3    -18    -10    -12    -24    -20
LINKED TO       -27
EXPOSURE         91     58    144     92     95     64    103     39     16    149
EXPOSURE        155    134     91    218    176    175    265    271    148    270
EXPOSURE        183
WEIGHTED         92     99    290    186     96     65    208     40     17    300
WEIGHTED        312    270     92    219    354    352    540    544    298    542
WEIGHTED        368

NODE NO.   31 TOTAL LINKS     6
X,Y,Z COORDINATE    8,   41,  300
LINKED TO        34     18     28     37    -24    -23
EXPOSURE        100     64     19      0    228     80
WEIGHTED        101    130     40      1    458     81

NODE NO.   37 TOTAL LINKS     7
X,Y,Z COORDINATE   21,   52,  300
LINKED TO        42     50     32     28    -40    -41    -42
EXPOSURE        100     40     36     28    255    183    166
WEIGHTED        202     41     74     58    256    368    167

NODE NO.   50 TOTAL LINKS     6
X,Y,Z COORDINATE   10,   65,  300
LINKED TO        52     42     56     57    -48    -40
EXPOSURE        100     93     10     58    219    193
WEIGHTED        202    100     22     59    440    308

NODE NO.   56 TOTAL LINKS     4
X,Y,Z COORDINATE    9,   76,  300
LINKED TO        52    -62    -45    -59
EXPOSURE        100    214    165    158
WEIGHTED        202    215    332    159

NODE NO.  -59 TOTAL LINKS     5
X,Y,Z COORDINATE   23,   85,  350
LINKED TO        57     60    -62    -64    -71
EXPOSURE        100    147    165    187     39
WEIGHTED        101    256    332    188     80

NODE NO.  -71 TOTAL LINKS     5
X,Y,Z COORDINATE   10,   96,  350
LINKED TO        70    -62    -76    -74    -78
EXPOSURE        100    236    120    129     47
WEIGHTED        202    237    121    130     48
```

Table A.12. (cont'd.)

NODE NO. -78 TOTAL LINKS 6
X,Y,Z COORDINATE 22, 108, 340

LINKED TO	84	75	82	-74	-76	-79
EXPOSURE	90	70	17	195	112	0
WEIGHTED	91	71	36	392	226	1

NODE NO. -79 TOTAL LINKS 9
X,Y,Z COORDINATE 37, 116, 330

LINKED TO	86	87	72	75	84	74	96	-85	-74
EXPOSURE	100	88	90	90	80	62	44	90	96
WEIGHTED	101	89	91	182	162	126	90	91	194

NODE NO. 87 TOTAL LINKS 6
X,Y,Z COORDINATE 45, 121, 320

LINKED TO	86	85	90	-85	-88	-75
EXPOSURE	132	40	38	119	105	96
WEIGHTED	133	41	39	240	110	194

NODE NO. 90 TOTAL LINKS 6
X,Y,Z COORDINATE 58, 122, 310

LINKED TO	85	91	86	83	-88	-77
EXPOSURE	132	103	77	8	121	96
WEIGHTED	133	104	156	9	244	194

NODE NO. 83 TOTAL LINKS 8
X,Y,Z COORDINATE 70, 114, 300

LINKED TO	91	73	88	85	80	-77	-81	-75
EXPOSURE	124	98	91	63	35	138	53	97
WEIGHTED	250	158	92	128	36	278	54	196

NODE NO. 80 TOTAL LINKS 6
X,Y,Z COORDINATE 83, 110, 300

LINKED TO	71	73	88	79	89	-81
EXPOSURE	100	105	133	33	154	156
WEIGHTED	202	212	268	34	155	157

NODE NO. 79 TOTAL LINKS 10
X,Y,Z COORDINATE 97, 108, 300

LINKED TO	81	71	67	77	89	93	66	-82	-69	-81
EXPOSURE	179	108	124	135	207	191	51	271	94	109
WEIGHTED	180	76300	37500	13600	62400	19200	15600	816	47500	55000

Case 8 - Area 2, Route 2, Sensor Set 2.

Table A.13. Case 8 - Node Linkage for Route

FROM	EASTING	NORTHING	TO	PENALTY	EASTING	NORTHING
35	2770	10500	28	1	3610	9660
28	3610	9660	37	67	3470	10640
37	3470	10640	30	2	2560	9870
30	2560	9870	15	50	25[illegible]	9030
15	2580	9030	9	7	4870	7630
9	4670	7630	12	1	4450	8470
12	4450	8470	7	50	5290	7630
7	5290	7630	-2	40	4240	7280
-2	4240	7280	10	101	4100	7980
10	4100	7980	31	37	4240	10080
31	4240	10080	36	52	5290	10640
36	5290	10640	46	119	5500	11270
46	5500	11270	34	8	4730	10430
34	4730	10430	32	156	5500	10150
32	5500	10150	-21	56	5010	9100
-21	5010	9100	11	34	5430	8190
11	5430	8190	21	19	5570	9170
21	5570	9170	19	110	4100	9100
19	4100	9100	-23	72	3120	9240
-23	3120	9240	22	18	4170	9240
22	4170	9240	42	34	2980	11060
42	2980	11060	33	64	2280	10360
33	2280	10360	56	34	2630	12320
56	2630	12320	50	29	3260	11550
50	3260	11550	57	59	3890	12390
57	3890	12390	-62	110	2840	13090
-62	2640	13090	70	2	2210	14000
70	2210	14000	81	1	2560	14910
81	2560	14910	96	1	3610	15960
96	3610	15960	105	1	4660	17010
105	4660	17010	91	1	6620	15540
91	6620	15540	88	59	7670	15470
88	7670	15470	63	22	6500	14580
63	6900	14980	60	46	7810	14700
80	7810	14700	79	34	8790	14560
79	6790	14560	66	52	9840	13510
66	9840	13510	76	144	10610	14420
76	10610	14420	84	191	10560	14580

Table A.14. Case 8 - Node Linkage

```
NODE NO.   35 TOTAL LINKS    8
X,Y,Z COORDINATE    11,   50,  300
LINKED TO        33      42      30      37      50      28     -42     -45
EXPOSURE        100      66      77      69       4       0     193     154
WEIGHTED        202      87     156     140       5       1     388     310

NODE NO.   28 TOTAL LINKS    7
X,Y,Z COORDINATE    23,   38,  300
LINKED TO        22      19      31      15      37      30     -23
EXPOSURE        134      76     121     137      66      47     195
WEIGHTED        135      77     244     276      67      96     392

NODE NO.   37 TOTAL LINKS    7
X,Y,Z COORDINATE    21,   52,  300
LINKED TO        42      50      31      30     -40     -41     -48
EXPOSURE        100      47      43       0     256     193     178
WEIGHTED        202      48      88       2     257     388     179

NODE NO.   30 TOTAL LINKS    4
X,Y,Z COORDINATE     8,   41,  300
LINKED TO        33      15     -24     -23
EXPOSURE        100      24     214      50
WEIGHTED        101      50     430      51

NODE NO.   15 TOTAL LINKS   22
X,Y,Z COORDINATE    14,   29,  310
LINKED TO        19      22       8      33      10      12      31      42      34       9
LINKED TO       -23     -13     -24     -18      -3      -1     -26     -21      -2     -42
LINKED TO       -40     -41
EXPOSURE         61      73     114      60      59      41      54      37      28       6
EXPOSURE        132     130     211     220     179      98     197      86      48     160
EXPOSURE        177     171
WEIGHTED        124     148     230      61      60      84     110      38      58       7
WEIGHTED        133     262     424     442     360     198     396     174      98     161
WEIGHTED        178     172

NODE NO.    9 TOTAL LINKS    5
X,Y,Z COORDINATE    41,    9,  290
LINKED TO         7      11      10      12      -2
EXPOSURE        147      75      65       0     137
WEIGHTED        296     152     132       1     276

NODE NO.   12 TOTAL LINKS    6
X,Y,Z COORDINATE    35,   21,  290
LINKED TO        10      19      22      11       7     -21
EXPOSURE        124      79      87      53      24     156
WEIGHTED        250      80      88     108      50     314

NODE NO.    7 TOTAL LINKS    4
X,Y,Z COORDINATE    47,    9,  300
LINKED TO        11     -10      -2     -12
EXPOSURE        100     265      19     248
WEIGHTED        202     532      40     498

NODE NO.   -2 TOTAL LINKS    2
X,Y,Z COORDINATE    32,    4,  310
LINKED TO        10      -1
EXPOSURE        100      96
WEIGHTED        101     194

NODE NO.   10 TOTAL LINKS   18
X,Y,Z COORDINATE    30,   14,  300
LINKED TO        19      22       8      11      21      31     -13      -1     -21     -23
LINKED TO       -26      -3     -18     -10     -12     -24     -20     -27
EXPOSURE         91      57     143      91     100      36     149     154     133      89
EXPOSURE        216     173     172     266     267     144     266     178
WEIGHTED         92      58     288     184     202      37     300     310     260      90
WEIGHTED        217     348     346     534     536     290     534     358

NODE NO.   31 TOTAL LINKS    8
X,Y,Z COORDINATE    32,   44,  300
LINKED TO        34      22      19      36     -26     -40     -41     -21
EXPOSURE        116      79      39      25     249     205     208      65
WEIGHTED        234     160      80      52     250     206     209      66

NODE NO.   36 TOTAL LINKS   12
X,Y,Z COORDINATE    47,   52,  300
LINKED TO        32      34      45      46      38      47     -32     -39     -41     -43
LINKED TO       -27     -26
EXPOSURE        158      89     239     118     185     167     205     205     206     182
EXPOSURE        189     171
WEIGHTED        318     180     248     119    1860    1680    2060    2060     414    1830
WEIGHTED        308     344
```

Table A.14. (cont'd.)

NODE NO. 46 TOTAL LINKS 10
X,Y,Z COORDINATE 59, 61, 320

LINKED TO	45	47	36	34	-43	-53	-39	-52	-41	-32
EXPOSURE	257	215	187	3	223	230	204	190	182	164
WEIGHTED	516	2160	1880	8	2240	231	2050	382	366	330

NODE NO. 34 TOTAL LINKS 6
X,Y,Z COORDINATE 39, 49, 300

LINKED TO	32	45	-41	-26	-40	-27
EXPOSURE	78	185	267	242	222	175
WEIGHTED	158	186	268	486	446	352

NODE NO. 32 TOTAL LINKS 9
X,Y,Z COORDINATE 59, 45, 330

LINKED TO	21	38	-27	-32	-26	-39	-21	-43	-41
EXPOSURE	49	183	275	224	227	190	27	151	167
WEIGHTED	100	1840	552	2250	456	1910	56	1520	336

NODE NO. -21 TOTAL LINKS 6
X,Y,Z COORDINATE 43, 30, 330

LINKED TO	21	22	19	11	-26	-27
EXPOSURE	158	48	15	16	271	189
WEIGHTED	318	98	40	34	272	380

NODE NO. 11 TOTAL LINKS 4
X,Y,Z COORDINATE 45, 17, 300

LINKED TO	21	-12	-10	-20
EXPOSURE	18	346	335	254
WEIGHTED	19	694	680	510

NODE NO. 21 TOTAL LINKS 23
X,Y,Z COORDINATE 51, 31, 330

LINKED TO	27	13	22	19	38	45	2	3	-27	-20
LINKED TO	-26	-12	-32	-10	-35	-8	-15	-28	-37	-43
LINKED TO	-41	-40	-36							
EXPOSURE	337	321	74	54	214	183	76	69	278	354
EXPOSURE	254	321	233	309	212	288	300	312	220	193
EXPOSURE	190	175	195							
WEIGHTED	3380	644	150	110	2150	184	154	140	558	710
WEIGHTED	510	644	2340	620	2130	578	3010	3130	2210	1940
WEIGHTED	191	176	1960							

NODE NO. 19 TOTAL LINKS 4
X,Y,Z COORDINATE 30, 30, 250

LINKED TO	22	-26	-23	-13
EXPOSURE	100	200	35	39
WEIGHTED	101	402	72	80

NODE NO. -23 TOTAL LINKS 4
X,Y,Z COORDINATE 16, 32, 310

LINKED TO	22	-24	-13	-18
EXPOSURE	8	228	137	146
WEIGHTED	18	458	276	294

NODE NO. 22 TOTAL LINKS 21
X,Y,Z COORDINATE 21, 32, 300

LINKED TO	8	42	33	45	47	-26	-13	-27	-40	-41
LINKED TO	-24	-20	-18	-1	-32	-12	-10	-39	-3	-42
LINKED TO	-43									
EXPOSURE	96	33	32	187	167	270	113	235	216	219
EXPOSURE	175	300	186	91	196	279	271	183	156	156
EXPOSURE	171									
WEIGHTED	194	34	66	188	1680	542	228	472	217	220
WEIGHTED	352	602	374	184	394	560	272	1848	314	314
WEIGHTED	1720									

NODE NO. 42 TOTAL LINKS 7
X,Y,Z COORDINATE 14, 38, 300

LINKED TO	50	52	33	-42	-45	-40	-48
EXPOSURE	100	73	31	205	183	189	166
WEIGHTED	101	74	64	412	368	380	167

NODE NO. 33 TOTAL LINKS 11
X,Y,Z COORDINATE 4, 48, 300

LINKED TO	52	50	56	57	-42	-45	-24	-18	-40	-48
LINKED TO	-13									
EXPOSURE	61	58	33	58	249	233	210	196	205	190
EXPOSURE	62									
WEIGHTED	62	59	34	59	250	234	422	394	412	191
WEIGHTED	126									

NODE NO. 56 TOTAL LINKS 5
X,Y,Z COORDINATE 9, 76, 300

LINKED TO	52	58	-62	-45	-59
EXPOSURE	100	28	214	165	158
WEIGHTED	202	29	215	332	159

Table A.14. (cont'd.)

```
NODE NO.   50 TOTAL LINKS     4
X,Y,Z COORDINATE    18,   65,  300
LINKED TO        52      57     -48     -40
EXPOSURE        100      58     219     193
WEIGHTED        202      59     440     388

NODE NO.   57 TOTAL LINKS     6
X,Y,Z COORDINATE    27,   77,  330
LINKED TO        60     -59     -48     -52     -64     -62
EXPOSURE        172     160     143     122     191      54
WEIGHTED        173     322     288     246     192     110

NODE NO.  -62 TOTAL LINKS     3
X,Y,Z COORDINATE    12,   87,  350
LINKED TO        70     -71     -59
EXPOSURE          0     155     226
WEIGHTED          2     156     454

NODE NO.   70 TOTAL LINKS     3
X,Y,Z COORDINATE     3,  100,  330
LINKED TO        81     -71     -76
EXPOSURE          0     195      86
WEIGHTED          1     392      87

NODE NO.   81 TOTAL LINKS     6
X,Y,Z COORDINATE     8,  113,  330
LINKED TO        95      82      96     -76     -78     -74
EXPOSURE         57      49       0     147      97     127
WEIGHTED        116      50       1     296      98     256

NODE NO.   96 TOTAL LINKS     8
X,Y,Z COORDINATE    23,  128,  330
LINKED TO        82     102      95     105     -93     -85     -92     -79
EXPOSURE         63     149      54       0     190      54     140      24
WEIGHTED         64     150     110       1     382      55     282      50

NODE NO.  105 TOTAL LINKS    13
X,Y,Z COORDINATE    38,  143,  330
LINKED TO        87      86      90      85      82      95      91     -85     -88     -93
LINKED TO       -79     -95     -92
EXPOSURE         81      62      28      13      59      53       0     148     137     128
EXPOSURE         86     121      96
WEIGHTED        164     126      29      28     120     108       1     149     138     258
WEIGHTED         87     244     194

NODE NO.   51 TOTAL LINKS     6
X,Y,Z COORDINATE    66,  122,  310
LINKED TO        90      83      85      88     -87     -77
EXPOSURE        124      87      95      58     180      73
WEIGHTED        250     176     192      59     181     148

NODE NO.   88 TOTAL LINKS     6
X,Y,Z COORDINATE    81,  121,  320
LINKED TO        80      83      89     -81     -87     -90
EXPOSURE         29      10     116     139     146     150
WEIGHTED         60      22     117     140     294     151

NODE NO.   83 TOTAL LINKS     7
X,Y,Z COORDINATE    70,  114,  300
LINKED TO        73      85      80      90     -77     -81     -79
EXPOSURE        124      76      47      56     161      54      97
WEIGHTED        250     154      48     114     324      55     196

NODE NO.   80 TOTAL LINKS     5
X,Y,Z COORDINATE    83,  110,  300
LINKED TO        71      73      79      89     -81
EXPOSURE        100     105      33     154     186
WEIGHTED        202     212      34     155     157

NODE NO.   79 TOTAL LINKS     9
X,Y,Z COORDINATE    97,  108,  300
LINKED TO        71      67      77      89      93      66     -82     -69     -81
EXPOSURE        106     124     135     207     191      51     271      94     109
WEIGHTED        218     125     136     208     192      52     272     190     220
```

Table A.14. (cont'd.)

NODE NO. 66 TOTAL LINKS 9
X,Y,Z COORDINATE 112. 93. 290

LINKED TO	67	61	77	63	62	69	76	-72	-58
EXPOSURE	127	100	160	174	234	157	143	238	289
WEIGHTED	256	202	161	350	470	158	144	239	580

NODE NO. 76 TOTAL LINKS 9
X,Y,Z COORDINATE 123. 106. 300

LINKED TO	69	84	77	78	68	-72	-80	-84	-65
EXPOSURE	155	190	110	181	131	113	233	205	187
WEIGHTED	780	191	55500	54600	39600	79800	23400	61800	94000

APPENDIX B

FORTRAN PROGRAM FOR ROUTING MODEL

The program that has been developed as a result of this research is currently running on a CDC Cyber 7400 series machine. The programmed model has been tested on a ten kilometer area and was run for a 35 by 35 km area. The longest running feature of the model is the line of sight calculations. The model has 14 subroutines which are controlled by the main program and one subroutine. The relationship between the subroutines is shown in Figure B-1.

Within this appendix is a short discussion of the model. The basic purpose and operations of the various subroutines are given first. The arrays in COMMON and those that are not are defined. Also variables within COMMON are defined along with some which are used only in a single subroutine. With one exception, flow charts were not drawn for the model since the definition of the variables and the comments within the program itself should be sufficient. The logic of subroutine CLUST is not obvious, therefore a flow chart was drawn for this subroutine. Lastly, within this appendix is a listing of the Fortran computer code for the 10 by 10 km size model.

Main Program

The main program is an executive routine that directs the operation of the model. Five subroutines are called by the main program. The initial call is to INDATA which is a short subroutine that reads the terrain data. After this call the main program groups this elevation

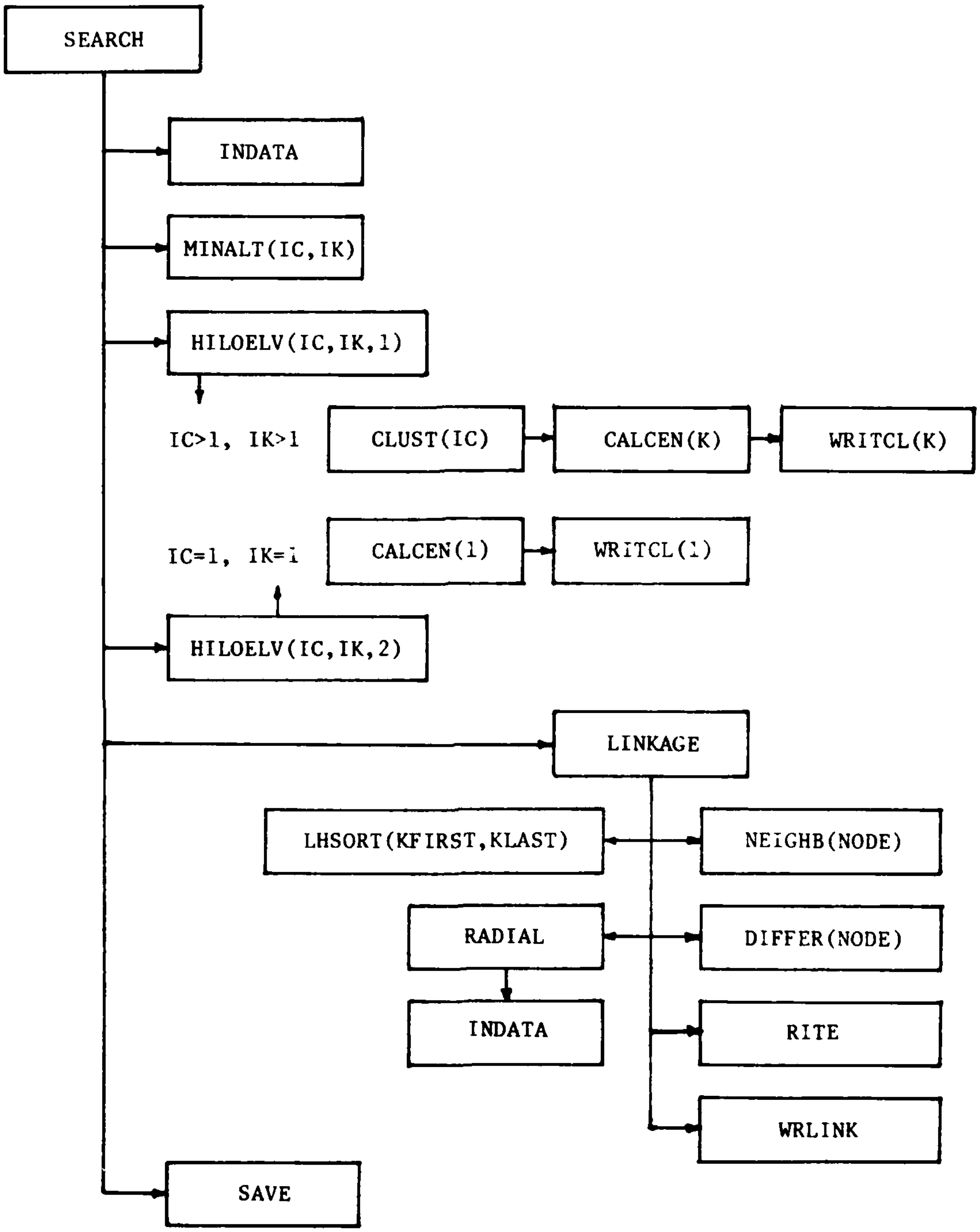

Figure B-1. Main Program and Subroutine Relationship.

data into elevation bands. Each sensor site's elevation is obtained from this data by finding the sensor's location within the elevation data array. A call is then made to the MINALT subroutine to determine both the maximum and minimum elevation groups within each elevation data array of 1 km square. Two calls are made to HILOELV subroutine; the first call is for processing the low elevation band and the second call is for the high elevation band. The next subroutine called is LINKAGE which is an executive subroutine that directs the routing process. If the results of route development are to be retained for further use, then SAVE can be called.

INDATA

This subroutine only reads the elevation data for the model. The terrain data is read in strips of 1 km wide and up to 50 km long. The data is stored into arrays of 15 by 15 data points and have a terrain interval of 70 meters between points. As each new strip of terrain is needed, a call is made to this subroutine.

MINALT

The minimum and maximum elevation data points in an array are found and stored in arrays in a packed format. The array ISET contains the row and column index of each low point and the array MSET contains the high points. The data is processed sequentially from the first terrain data array element such that if a new minimum or maximum is found, the pointers and counter are reset.

HILOELV

This subroutine is divided into two major parts. An IF test is performed on a call parameter ILO to determine whether the low

elevation (IC, — ,ILO=1) or high elevation data (— ,IK,ILO=2) is processed. The logic is the same for each part. A call is made to CLUST which identifies disjoint groups of elevation data. After finding the members of each cluster a call is made to CALCEN to calculate the cluster center. If there is only a single value in this cluster, CLUST is skipped and CALCEN is called directly. The values on these centers are then stored in LOWCEN or HICEN depending on which type of elevation data is being processed. After storing these values a return is made to the main program.

CLUST

Once the low or high data points are identified the cluster to which they belong is determined by the beginning and end of each data point string. The data points have been found sequentially; therefore, the breaks in adjacency of points define the cluster boundaries. Since the row and column indexes are stored by letting IVAL = (ROW * 100) + COLUMN, subtracting two consecutive values will indicate whether they are adjacent. When all the members of a cluster are found, a call is made to CALCEN to calculate the centroid of the cluster.

CALCEN

This subroutine calculates the centroid of the cluster found in CLUST. The mean of row indexes ($\bar{Y}$) and mean of column indexes ($\bar{X}$) are the values for the center of the cluster. Since the indexes are integer values, the sum of the indices has a half added to allow for truncation of the decimal portion. An IF test is made on the calculated indexes for the center to ensure that they are within the array dimensions. For debug purposes several write statements in this subroutine can be set.

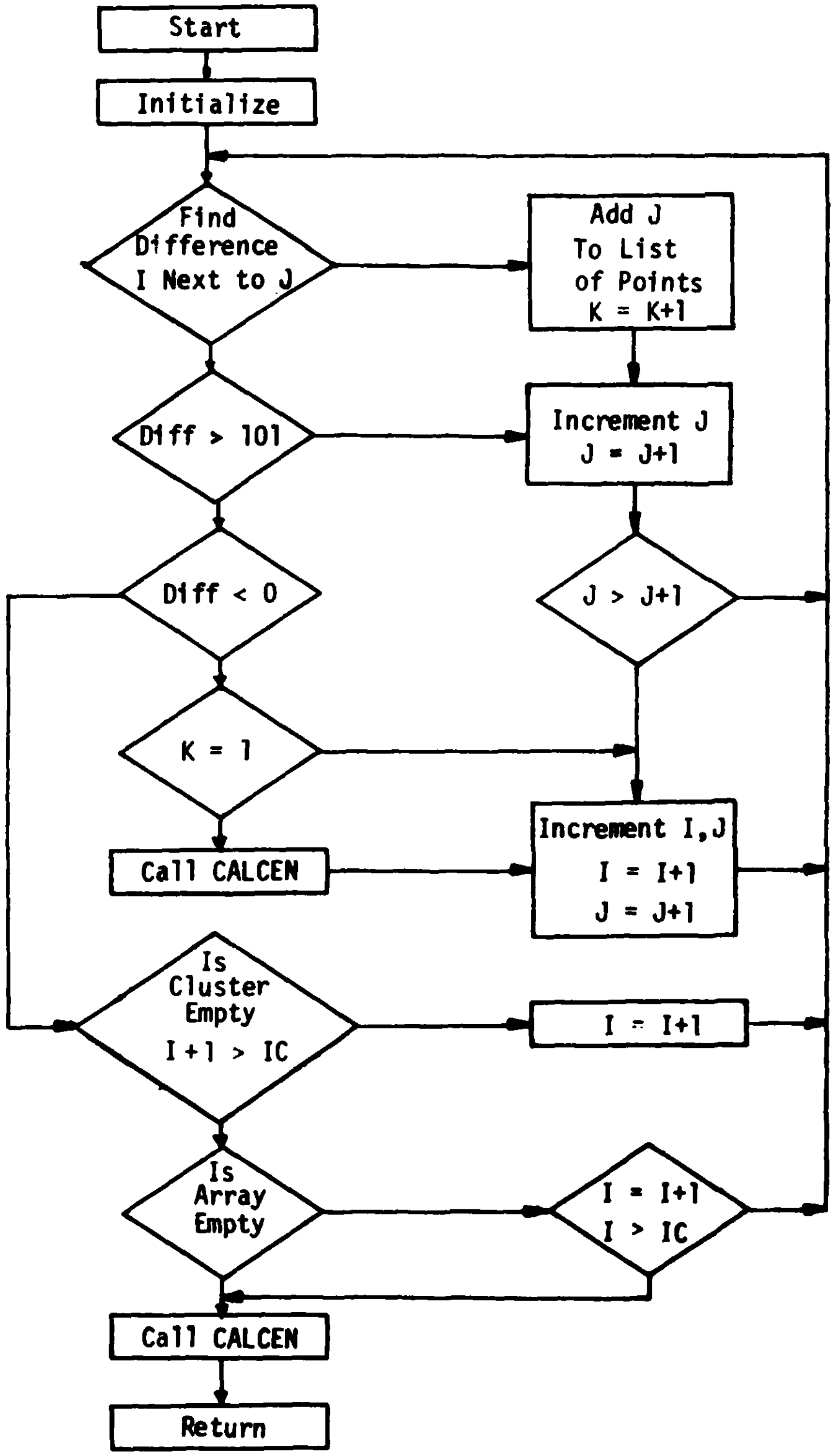

Figure B-2. Subroutine CLUST.

WRITCL

To list the clusters and centers this subroutine can be called letting LWRIT $\geq$ 3. The low (or high) elevation cluster and pointers to the cluster members are listed. When this routine is called, LH is checked to decide whether high or low elevation values are to be printed.

LINKAGE

Once all the high and low elevation centers have been found, the main program calls this subroutine. The remaining portion of the model is directed by LINKAGE. The first subroutine it calls is LHSORT to sort the high and low lists of centers. Then subroutine RADIAL is called to determine the LOS between each node point and each sensor. RADIAL also calculates the first part of the penalty function.

The routine now processes each route node by finding all other node points which are within 1 km. These other nodes are the neighborhood of points that have possible links between them and the current node being evaluated. Two arrays, LINK and LINKTO, are used to store which nodes are in the neighborhood, the penalty value associated with the nodes and a beginning of the list for each node. The high nodes are identified by a minus sign. Having defined the neighborhoods and penalty values for each point in the neighborhood, the route node is selected. Control is then returned to the main program.

RADIAL

This subroutine is the most time consuming of the model. To determine visibility of two terrain points requires more effort than would seem to be necessary. The first problem is to locate where the two points are in the terrain data base. Along the vector connecting

these points a search is made for any terrain feature that would block the line of sight.

The subroutine first determines whether the sensor or the node is the westernmost point. If necessary the logic will swap the two points to set the node as the western point and the sensor as the eastern point. Having established the ends of the LOS vector, the tangent from the horizontal and the sine and cosine are calculated.

With those parameter values the routine begins the search along the vector. The vector is tested to locate its direction. Depending on whether it's between 0°-45°, 45°-135°, or 135°-180° will give a heading of north, east or south respectively. The calculations used are given in section 4.3.

The routine finishes by listing the exposure values calculated for the number of sensors that can see each node. These values will then be used by DIFFER for those nodes which lie along the route corridor.

LHSORT

The initial point and the terminal point are added to the list of low elevation centers. The low elevation centers (nodes) are sorted into ascending order by row. This sorting is to ease the logic for the model. After the low centers are finished the high elevation centers are sorted in the same manner. Pointers KFIRST and KLAST are used to locate the initial and terminal nodes and are set after the sorting of LOWCEN. The lists of low and high nodes are written out as tables before returning to LINKAGE.

NEIGHB

To define a neighborhood it was found that the normal visual search pattern is limited to 1 km. The nodes which lie within 1 km are considered

to be neighbors of the current node. The resulting area is a 2 km square with the principle node in the center. Having sorted the arrays of centers, only 15 rows in either direction from the current row are searched for a neighbor. For any row that is searched, only those nodes which are within 15 columns on either side of the current node are retained as neighbors. When both the low and high centers that are in the neighborhood have been found, they are stored for use by subroutine DIFFER. The results can be listed by having LWRIT $\geq$ 2.

DIFFER

For each neighborhood the distance from the current (primary) node is calculated and stored. The DIST array retains the distances for low centers in the first column and the high centers in the second column. The minimum and maximum distance and elevation are found while the distance between node points is calculated. Once these values are obtained they are sorted in ascending order by distance. A value of LWRIT $\geq$ 2 will allow the printing of these results. The routine then completes the calculation of the exposure value for these nodes using the values stored by RADIAL.

RITE

This routine will write several of the large arrays to temporary storage if there are more values than the arrays can handle. These data are then read back into the program as needed on top of those values no longer needed.

SAVE

This routine will save the route and linkage arrays for plotting. A TAPE 7 is set up to store the data in a format for plotting the X-Y

coordinates of the nodes. The routine can be easily modified to write any data that should be retained.

WRLINK

After the route has been found, this routine will list the linkage information used in constructing the route. Listed are the arrays, the pointers and nodes with their exposure values.

Arrays in COMMON

IDATA(I,J,K)	This array contains terrain elevation values. It is a three dimensional array where the index K indicates the map sheets. The initial values are reassigned based on the equation given in section 4.2
LOWCEN(I,J,K)	The X, Y and Z coordinate of the low elevation nodes are stored in this array. Index I contains the Y value, J contains the X value, and K contains the Z value.
HICEN(I,J,K)	This array is just like LOWCEN except it contains the X, Y and Z coordinate of the high elevation nodes.
IPOINT(I)	This array is used throughout the model to store pointers.
ISET(I)	The row and column indexes of each cluster member are packed into this array. The first time used it contains low elevation points. The second time it contains the high elevation points.
MSET(I)	This array stores the high elevation cluster members for use by ISET.
CEROID(X,Y,Z)	As the centers for the low and high centers are being calculated CEROID is used to temporarily store them before placing them in either LOWCEN or HICEN.
ISITE(I,J,K)	The location of the sensors are stored in this array. Up to 10 sensors can be used as currently dimensioned.
INITIAL(I)	The location of the starting point for the route is entered into this array.
LAST(I)	The terminal point for the route is stored in this array.
LINK(I)	This array contains the pointers to the entries of LINKTO. The value in location I gives the beginning of the node list in LINKTO that is associated with node I of array FROM.

LINKTO(I,J,K)	This array has the node number of the nodes linked to node I of FROM. J is the exposure value of that node and K is the weighted exposure value.
FROM(I)	The route nodes are stored in order of occurence in this array. If I is the tenth entry then this node number is the tenth node of the route.
TO(I,J)	The first entry I contains the node that is reached from the FROM(I) node. The value stored in J is the weighted exposure for the node traveled to FROM(I).
DETLO(I)	The visibility value for a low elevation node is stored in this array.
DETHI(I)	The visibility value for a high elevation node is contained in this array.
DIST(I,J)	The distance between a primary route node and the neighborhood nodes are stored in DIST. The I value is for low elevation nodes and the J value is for high elevation nodes.
SYSR(I)	This array has the weapon system kill radius in km. This value is converted to the units used by the model. If the first value is zero, then radar avoidance weighting is not used.
SR(I,J)	The range between the current node and the sensor, the angle to the sensor and the angle of coverage are stored in this array. This information is used for the radar avoidance weighting.

<u>Arrays not in COMMON</u>

MPOINT(I)	For small lists which need pointers this array is set equivalent to the last part of IPOINT to save core storage. This array is used in several subroutines in this manner.
IFINISH(I)	To keep up with the progress of the LOS calculations in RADIAL, this array has the bits of an array element set to one as each node-sensor pair is completed. The zero through nine bit are used for low elevation nodes and up to 10 sensors. The ten through nineteen bit are used for high elevation nodes.
NLIST(I)	After the route is found, the smoothing routine stores the modified route in this array.

Variables in COMMON

JSTRIP	The current map sheet that is being used by the model.
KCET	The number of clusters that are found is stored in this variable until it can be added to either NLOW or NHI depending on whether it is low or high elevation clusters.
NLOW	This variable is the total number of low elevation nodes found plus the initial and final route nodes.
NHI	The total number of high elevation nodes found is stored in this variable.
SMAX	As the node-sensor combinations are being processed the maximum distance is checked. If a distance is found which is greater than SMAX then the new value is assigned to SMAX.
NBLKS	This variable is the number of data blocks written on to temporary storage.
LWRIT	This variable is used to obtain detail data on the operations of the model. It is mainly used for checking results. IF LWRIT > 5 then everything is printed. As this variable increases in value the amount of printing decreases. A value over 3 turns off the detail printing.
LDEBG	To debug the clustering portion of the model this variable can be set ≠ 1.
LALT	The minimum elevation for the map sheet currently being used.
HALT	The maximum elevation for the current map sheet.
LH	If LH is set to 1 then low elevation points are being processed. IF LH is 2 then high elevation points are being processed.
SENALT	The altitude of the sensor above local terrain is entered in this variable.
VEHALT	The vehicle altitude it will be flying above local terrain. Can be used for a ground vehicle by setting it to zero.
NSITE	The number of sensors that are located in the area of interest. A maximum of ten can currently be used.

RE	This variable is the radius of the earth for use in the LOS calculations to allow for earth curvature.
MDIM	This variable is the number of data points in the terrain data array. It is now set for a 15 by 15 array.
GRID	The grid interval (in meters) between the terrain data points. From this research the grid interval was 70 meters.
SWEA	The easting of the southwest corner of the terrain area being analyzed.
SWNR	The northing of the southwest corner.
LTRS	The UTM letter designation for the grid zone of the southwest corner.
IRADUS	The radius value to be used to determine a neighborhood of nodes. A value of 15 (1 km) is currently being used.
LNEBR	The number of low elevation nodes within the neighborhood for the current route node being evaluated.
KNEBR	The number of high elevation nodes within the neighborhood.
IROW	The row value (y-axis) of the current route node being evaluated.
JCOL	The column (x-axis) of the current route node being evaluated.
KFIRST	The location of the initial route node within the LOWCEN array.
KLAST	The location of the terminal or destination node within the LOWCEN array.
IC	The number of nodes that the route passes through.
IFREE	The total number of linkages that were found as the route was being developed.
RANGE	The range at which the weighting scheme narrows the search area down. When the terminal point is within 1 km of the current position the field of view is narrowed down to 90°. Node points outside these parameters have a higher weight assigned to them.

KMAT	The maximum number of terrain data arrays in the north-south direction is assigned this variable.
ISTRIP	This variable is set equal to the number of map sheets being used.
JMAT	The current array within a map sheet that is being used by the model.
RATE	The distance between terrain points in the data base that are being used. In this research every data point is used thus RATE is set to one.

Subroutine RADIAL Variables

NORTH SOUTH EAST WEST	These variables are the map sheet boundaries and the names correspond to the boundary edge.
ZCURVE	This parameter is a logical value that be set if curvature of the earth is used for LOS calculations.
DZ	The amount of curvature that is present when correcting for earth curvature.
XSIT,XP YSIT,YP ZSIT,ZP KSIT	These variables are the X, Y and Z coordinates of the sensor that is currently being used in the LOS calculations. The KSIT value is the integer value of XSIT.
XS1 YS1 ZS1 KS1	These variables are the X, Y and Z coordinates of the current node being processed by RADIAL. The KS1 is the integer value of XS1.
XSP YSP ZSP	The difference between the sensor and node are found for each coordinate and stored in these variables.
DIS RMAX	This variable is the vector distance between the sensor and node in the X-Y plane. RMAX is set equivalent to DIS.
R	This variable is the vector distance from the node to the terrain point in the data base that LOS is being checked.
TM	The tangent to the eastern point from the horizontal is stored in this variable.
T	The tangent to the terrain is calculated and stored in variable for comparison with TM.
YWEST	The Y component of the tangent T on the west map edge is contained in this variable to correct for vector crossing map sheets.
Z	The elevation of the current terrain point being checked for masking is assigned to this variable.

XSIN	The sine of the azimuth angle measured clockwise from north for the node-sensor vector is stored in this variable.
YCOS	This variable is the cosine of the azimuth angle.
ZNORTH ZSOUTH	These variables are logicals to indicate whether the vector is heading north or south.
NAR	This variable is the array within the map sheet where the terrain point is located.
X,IX	These variables are the x coordinate for the current terrain point.
Y,JY	These variables are the y coordinate for the current terrain point.
IDX,JDY	These variables are the increment in X and Y respectively.
IFIN	This variable is used to check for completion of a sensor-node pair.
IEXP	The sensor bit in IFINISH is set by using the exponent of 2 corresponding to the bit location in the computer word.
RTOD	This variable is the number of radians to degrees.
EAST1 NORTH1	The easting and northing of the beginning of a route segment or path leg along the route.
EAST2 NORTH2	The easting and northing of the end node of the route segment that begins at EAST1,NORTH1.

Subroutine DIFFER Variables

DMIN	The minimum distance between any node in the neighborhood of the current route node being processed.
DMAX	The maximum distance between any node in the neighborhood of the current route node being evaluated.
DRANG	The difference between DMAX and DMIN is assigned this variable.
KZMIN	The minimum elevation for any node in the neighborhood for the route node being evaluated.

KZMAX — The maximum elevation for any node in the neighborhood for the route node being evaluated.

KZRANG — The difference of KZMAX less KZMIN is assigned this variable.

Subroutine LINKAGE Variables

NWEIG — This variable is the weight a node point has because of its location with respect to the current route node.

IFLAG — If the procedure cannot find any node points in a neighborhood of a route point, the rectilinear distance for a neighborhood is doubled. IFLAG is then set to -1 and the model stops if no nodes still cannot be found.

NPEN — This variable is the weight exposure value the penalty function calculates for the node in the neighborhood.

LPEN — This variable is used to store the current minimum NPEN that has been found.

NEWPT — The node in the neighborhood with the current minimum exposure is assigned to NEWPT.

XI,IX — The X coordinate difference between the route node and the neighborhood node is stored in these variables.

YJ,JY — The Y coordinate difference for the same two nodes as XI above.

KANG — The angle at which the terminal node lies from the current route node is measured from the x-axis and assigned to KANG.

IANG — This angle is the direction of a neighborhood node from the route node.

IAK — This angle is the difference between KANG and IANG.

RANG — The range from the route node to the terminal node is stored in this variable.

RA — This range is from the route node to the neighborhood node.

FORTRAN LISTING

```
      PROGRAM SEARCH(INPUT=/80,OUTPUT=/137,TAPE5=INPUT,
     1 TAPE6=OUTPUT,TAPE7,TAPE8,TAPE9)
      COMMON/IDAT/  KMAT,ISTRIP,IDATA(15,15,10)
      COMMON/LCENT/ LOWCEN(250,3),HICEN(250,3),KCET,NLOW,NHI,
     1    SMAX,LWRIT,LDEBG,JMAT,JSTRIP,LH
      COMMON/POINT/ INITIAL(3),LAST(3),IPOINT(250),
     1 ISET(250),MSET(250),CEROID(250,3)
      COMMON/SENVEH/ LALT,HALT,SENALT,VEHALT,IFREE,GRID,
     1 SWEA,SWNR,LTRS
      COMMON/SRAD/ RANGE,RE,MDIM,RATE,NSITE,ISITE(10,3),SYSR(10)
      INTEGER HALT,CEROID,HICEN,GRID,SWEA,SWNR,SAVETP
      INTEGER SENALT,VEHALT
      DATA INT,KMAT,ISTRIP,GRID,RANGE/10,10,10,70,14.3/
      DATA KCET,LWRIT,LDEBG,NLOW,NHI/0,1,1,0,0/
C
C *** KMAT IS SET UP FOR 10 ARRAYS WITHIN A STRIP OF DATA  **
C *** ISTRIP IS SET UP FOR 10 STRIPS  **
C
      NSITE = 3
      LWRIT = 3
      LDEBG = 1
C
C *** READ INPUT DATA  **
C
      READ(5,900) ISTRIP,KMAT,SAVETP,LWRIT,LDEBG
      READ(5,901) INT,GRID,LTRS,SWEA,SWNR
      READ(5,902) SENALT,VEHALT,IRADUS,RANGE,RE,RATE,MDIM
      READ(5,903) INITIAL(2),INITIAL(1),INITIAL(3)
      READ(5,903) LAST(2),LAST(1),LAST(3)
      READ(5,904) NSITE
      IF(NSITE .GT. 10) GO TO 1200
  100 DO 125 I=1,NSITE
      READ(5,903) ISITE(I,2),ISITE(I,1),ISITE(I,3)
      READ(5,905) SYSR(I)
  125 SYSR(I) = SYSR(I)*1000.0/GRID
C
      WRITE(6,910)
      DO 1000 JK=1,ISTRIP
      JSTRIP = JK
      CALL INDATA
C
C *** GROUP DATA INTO ALTITUDE BANDS                         **
C *** INT IS THE BAND INTERVAL                               **
C *** JMAT IS THE MATRIX BEING SUBDIVIDED FOR ANALYSIS       **
C
      DO 660 I=1,15
      DO 660 J=1,15
      DO 660 K=1,KMAT
  660 IDATA(I,J,K)=(((IDATA(I,J,K)-1)/INT)*INT)+INT
C
C *** FIND THE LOCATION OF THE SENSORS IN THE TERRAIN DATA  **
C
```

```
      DO 700 I=1,NSITE
      ICOL = JK*15
      NX = ISITE(I,2)
      IF(NX .GT. ICOL) GO TO 700
      ICOL = (JK-1)*15
      IF(NX .LT. ICOL) GO TO 700
      NX = NX-(JK-1)*15
      NY = ISITE(I,1)
      NZ = (NY-1)/15
      NY = NY-NZ*15
      NZ = NZ+1
      ISITE(I,3) = IDATA(NY,NX,NZ)
  700 CONTINUE
      IF (LWRIT .LE. 4) GO TO 675
      DO 501 K=1,KMAT
      WRITE(6,911)
  501 WRITE(6,912) ((IDATA(I,J,K),J=1,15),I=1,15)
      WRITE(6,910)
C
C *** MINALT FINDS MIN AND MAX ELEVATION IN EACH ARRAY    **
C *** HILOELV OVERSEE THE CLUSTERING OF ELEVATION BANDS   **
C
  675 DO 800 JJ=1,KMAT
      JMAT = JJ
      IC=1
      IK=1
      CALL MINALT(IC,IK)
      CALL HILOELV(IC,IK,1)
      IF(IC .EQ. 225) GO TO 800
      CALL HILOELV(IK,IK,2)
  800 CONTINUE
 1000 CONTINUE
      WRITE(6,910)
      WRITE(6,915) ISTRIP,KMAT,SAVETP,LWRIT,LDEBG
      WRITE(6,916) INT,GRID,LTRS,SWEA,SWAR
      WRITE(6,917) SENALT,VEHALT,IRADUS,RANGE,RE,RATE,MDIM
      WRITE(6,918) INITIAL(2),INITIAL(1),INITIAL(3)
      WRITE(6,919) LAST(2),LAST(1),LAST(3)
      WRITE(6,913)
      DO 1100 I=1,NSITE
 1100 WRITE(6,920) ISITE(I,2),ISITE(I,1),ISITE(I,3),SYSR(I)
      CALL LINKAGE
      IF(SAVETP .GT. 0) CALL SAVE
      STOP
 1200 WRITE(6,914) NSITE
      NSITE = 10
      GO TO 100
C
  900 FORMAT(5I5)
  901 FORMAT(2I5,10X,A2,2I4)
  902 FORMAT(3I5,3F10.3,I5)
  903 FORMAT(3I10)
```

```
904 FORMAT(I5)
905 FORMAT(F10.2)
910 FORMAT(1H1)
911 FORMAT(/10X,*ALTITUDE ARRAY*/)
912 FORMAT(15(1X,I6))
913 FORMAT(20X,*SENSOR LOCATION*/24X,*X*,7X,*Y*,7X,*Z*,
   1 7X,*SYS R*)
914 FORMAT(/////5X,*NUNBER OF SITES GREATER THAN 10 -*,I6/
   1 6X,*NSITE SET TO 10*)
915 FORMAT(//20X,*INPUT DATA*/20X,*ISTRIP KMAT SAVETP *,
   1 *LWRIT LDEBG*/  20X,5(I5,1X))
916 FORMAT(/20X,*INT  GRID  LTRS SWEA SWNR*/
   1 20X,2(I5,1X),A2,2(1X,I5))
917 FORMAT(/20X,*SENALT VEHALT IRADUS RANGE   RE*,10X,
   1 *RATE MDIM*/20X,3(I5,1X),F8.3,1X,F10.2,1X,F8.3,1X,I6)
918 FORMAT(/20X,*INITIAL POINT ON ROUTE - X,Y,Z*/
   1 20X,3(I6,2X))
919 FORMAT(/20X,*DESTINATION POINT FOR ROUTE - X,Y,Z*/
   1 20X,3(I6,2X))
920 FORMAT(20X,3(I5,3X),F10.3)
    END
```

```
      SUBROUTINE HILOELV(IC,IK,ILO)
C
C *** THIS SUBROUTINE CONTROLS HIGH/LOW CLUSTERING   **
C *** IC IS THE NUMBER OF MEMBERS IN LOWCEN          **
C *** IK IS THE NUMBER OF MEMBERS IN HICEN           **
C *** LOWCEN CONTAINS THE LOW ELEVATION CENTROIDS    **
C *** HICEN CONTAINS THE HIGH ELEVATION CENTROIDS    **
C *** NLOW IS THE NUMBER OF LOWCEN CENTROIDS         **
C *** NHI IS THE NUMBER OF HICEN CENTROIDS           **
C *** KCET IS CURRENT COUNT OF CLUSTER MEMBERSHIP    **
C
      COMMON/ICAT/  KMAT,ISTRIP,IDATA(15,15,10)
      COMMON/LCENT/ LOWCEN(250,3),HICEN(250,3),KCET,NLOW,NHI,
     1   SMAX,LWRIT,LDEBG,JMAT,JSTRIP,LH
      COMMON/POINT/ INITIAL(3),LAST(3),IPOINT(250),
     1 ISET(250),MSET(250),CEROID(250,3)
      COMMON/SENVEH/ LALT,HALT,SENALT,VEHALT,IFREE,GRID,
     1 SWEA,SWNR,LTRS
      INTEGER HALT,CEROID,HICEN
C
      IF(ILO .EQ. 2) GO TO 20
C
C *** PROCESS LOWCEN   **
C *** IF IC=1 ONLY ONE VALUE WAS FOUNDR MEMBERSHIP            **
C *** IF IC=225 THEN ALL THE ELEVATION VALUES ARE THE SAME    **
C *** THE SAME LOGIC IS USED FOR IK                           **
C
      LH = 1
      IF(IC .EQ. 1)   GO TO 500
      IF(IC .EQ. 225) GO TO 550
      CALL CLUST(IC)
      GO TO 610
  500 IPOINT(1) = 1
      GO TO 600
  550 IPOINT(1) = 113
  600 CALL CALCEN(1)
  610 CONTINUE
C
C *** STORE NEW MEMBERS   **
      DO 625 L=1,KCET
      LOWCEN(NLOW+L,1) = CEROID(L,1)
      LOWCEN(NLOW+L,2) = CEROID(L,2)
  625 LOWCEN(NLOW+L,3) = CEROID(L,3)
      NLOW = NLOW+KCET
      KCET = 0
      DO 650 L=1,250
      ISET(L) = 0
  650 IPOINT(L) = 0
      RETURN
C
C *** PROCESS HICEN   **
C
```

```
   20 LH = 2
      DO 100 I=1,IK
  100 ISET(I) = MSET(I)
      IF(IK .EQ. 1)   GO TO 700
      IF(IK .EQ. 225) GO TO 750
      CALL CLUST(IK)
      GO TO 810
  700 IPOINT(1) = 1
      GO TO 800
  750 IPOINT(1) = 113
  800 CALL CALCEN(1)
  810 CONTINUE
C
C *** STORE NEW MEMBERS  **
      DO 825 L=1,KCET
       HICEN(NHI+L,1) = CEROID(L,1)
       HICEN(NHI+L,2) = CEROID(L,2)
  825  HICEN(NHI+L,3) = CEROID(L,3)
      NHI = NHI+KCET
      KCET = 0
      DO 850 L=1,250
      ISET(L) = 0
  850 IPOINT(L) = 0
      RETURN
      END
```

```
      SUBROUTINE INDATA
      COMMON/IDAT/  KMAT,ISTRIP,IDATA(15,15,10)
      COMMON/LCENT/ LOWCEN(250,3),HICEN(250,3),KCET,NLOW,NHI,
     1   SMAX,LWRIT,LDEBG,JMAT,JSTRIP,LH
      INTEGER HALT
C
C *** READ INPUT TERRAIN DATA  **
C
      READ(8) LALT,HALT
      DO 600 IMAT=1,KMAT
  600 READ(8) ((IDATA(IROW,ICOL,IMAT),IROW=1,15),ICOL=1,15)
      RETURN
      END
```

```
      SUBROUTINE MINALT(IC,IK)
C
C *** THIS SUBROUTINE FINDS THE MIN AND MAX ELEVATION   **
C *** BANDS IN EACH JMAT ARRAY OF IDATA. IVAL IS THE    **
C *** ARRAY ELEMENT THAT IS BEING CHECKED FOR MIN/MAX   **
C
      COMMON/LCENT/ LOWCEN(250,3),HICEN(250,3),KCET,NLOW,NHI,
     1   SMAX,LWRIT,LDEBG,JMAT,JSTRIP,LH
      COMMON/POINT/ INITIAL(3),LAST(3),IPOINT(250),
     1 ISET(250),MSET(250),CEROID(250,3)
      COMMON/IDAT/  KMAT,ISTRIP,IDATA(15,15,10)
      INTEGER CEROID,HICEN
C
      DO 5 I=1,250
      MSET(I) = 0
    5 ISET(I) = 0
   20    IFF   = 1
         IL    = 15
         JF    = 1
         JL    = 15
  600 MIN VAL = 999999
      MAX VAL = -999999
C
C *** FOR IVAL                                          **
C *** A POSITIVE VALUE INDICATES IVAL OUTSIDE CLUSTER   **
C *** A ZERO VALUE - IVAL IN CLUSTER                    **
C *** A NEGATIVE VALUE INDICATES A NEW CLUSTER          **
C
      DO 800 I=IFF,IL
      DO 800 J=JF,JL
      IVAL=IDATA(I,J,JMAT)
      IF(IVAL - MIN VAL) 700,750,625
  625 IF(MAX VAL - IVAL) 650,660,800
C
C *** STORE INDICES FOR I AND J WITH MAXIMAL VALUE IN MSET  **
C *** IK IS A COUNT OF THE VALUES FOUND                     **
C
  650 IK = 0
      MAX VAL = IVAL
  660 IK = IK+1
      MSET(IK) = I*100+J
      GO TO 800

C
C *** STORE INDICES FOR I AND J WITH MINIMAL VALUE IN ISET  **
C *** IC IS A COUNT OF THE VALUES FOUND                     **
C
  700 IC=0
      MIN VAL = IVAL
  750 IC = IC+1
      ISET(IC) = I*100+J
  800 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE CLUST(IC)
      COMMON/LCENT/ LOWCEN(250,3),HICEN(250,3),KCET,NLOW,NHI,
     1   SMAX,LWRIT,LDEBG,JMAT,JSTRIP,LH
      COMMON/PCINT/ INITIAL(3),LAST(3),IPOINT(250),
     1 ISET(250),MSET(250),CEROID(250,3)
      INTEGER CEROID,HICEN
C
C *** THIS SUBROUTINE FINDS THE MEMBERS OF EACH CLUSTER            **
C *** IPOINT STORES THE INDEX OF ISET FOR THE CURRENT CLUSTER      **
C *** I IS THE BEGINNING OF THE ISET CLUSTER                       **
C *** J IS THE CURRENT VALUE IN ISET BEING EVALUATED               **
C *** FOR INCLUSION IN THE CLUSTER                                 **
C
      I=1
   30 K=1
      IPOINT(1)=I
   35 J = I+1
   40 IVAL = ISET(J)-ISET(I)
   52 IF((IVAL.EQ.1).OR.(IVAL.EQ.99).OR.(IVAL.EQ.100).OR.
     1   (IVAL.EQ.101)) GO TO 60
C
C *** TRUE -  INCREMENT I          **
      IF(IVAL .GT. 101) GO TO 54
C
C *** TRUE - J IS PAST LAST ENTRY   **
      IF(IVAL .LE. 0)    GO TO 82
      J = J+1
      IF( J .GT. (I+16)) GO TO 70
      GO TO 40
   54 IF((I+1) .EQ. J) GO TO 85
      I = I+1
      GO TO 35
C
C *** PLACE IVAL INTO CLUSTER USING ITS INDEX   **
C
   60 DO 62 L=1,K
   62 IF(IPOINT(L) .EQ. J) GO TO 64
      K = K+1
      IPOINT(K) = J
   64 J = J+1
      GO TO 40
C
C *** NO CHANGE IN K INDICATES THAT NO NEW MEMBERS EXIST   **
   70 IF(K .EQ. 1)  GO TO 75
        I = I+1
        GO TO 35
C
C *** ISOLATED POINT   ***
   75 CALL CALCEN(1)
      I = I+1
      IF(I .GT. IC) RETURN
      GO TO 30
```

```
   82 IF((I+1) .LT. IC) GO TO 84
      DO 83 L=1,K
   83 IF(IPCINT(L) .EQ. (J-1)) GO TO 90
      I = I+1
      IF(I .GT. IC) GO TO 90
      GO TO 35
   84 I = I+1
      GO TO 35
   85 CALL CALCEN(K)
      I = I+1
      GO TO 30
C
C *** END CLUSTER   ***
C
   90 CALL CALCEN(K)
      RETURN
      END
```

```
      SUBROUTINE CALCEN(K)
C
C *** DETERMINE THE CENTROID OF THE CLUSTER  ***
C
      COMMON/IDAT/ KMAT,ISTRIP,IDATA(15,15,10)
      COMMON/LCENT/ LOWCEN(250,3),HICEN(250,3),KCET,NLOW,NHI,
     1   SMAX,LWRIT,LDEBG,JMAT,JSTRIP,LH
      COMMON/POINT/ INITIAL(3),LAST(3),IPOINT(250),
     1 ISET(250),MSET(250),CEROID(250,3)
      COMMON/SENVEH/ LALT,HALT,SENALT,VEHALT,IFREE,GRID,
     1 SWEA,SWNR,LTRS
      INTEGER CEROID,HICEN,HALT
C
C *** INUM IS THE ROW INDEX - Y COORD      **
C *** JNUM IS THE COLUMN INDEX - X COORD   **
C
      KDUM = 0
      JNUM = 0
      INUM = 0
      KCET = KCET+1
C
C *** CALCULATE THE MEAN VALUES  **
C
      DO 100 L=1,K
       LL   = IPOINT(L)
       KDUM =  ISET(LL)/100
       JNUM = (ISET(LL) - KDUM *100) + JNUM
  100  INUM = KDUM + INUM
C
C *** THIS CALCULATION ADDS A HALF TO ALLOW FOR TRUNCATION  **
C
      JNUM = (2*JNUM+K)/(2*K)
      INUM = (2*INUM+K)/(2*K)
      IF(JNUM .GT. 15) JNUM=15
      IF(INUM .GT. 15) INUM=15
C
C *** NEED TO STORE WHICH ARRAY IS BEING PROCESSED  **
      IROW = (JMAT-1)*15+INUM
      ICOL = (JSTRIP-1)*15+JNUM
      CEROID(KCET,1) = IROW
      CEROID(KCET,2) = ICOL
      CEROID(KCET,3) = IDATA(INUM,JNUM,JMAT)
      IF(LWRIT .LE. 3) GO TO 10
      CALL WRITCL(K)
   10 IF(LDEBG .EQ. 1) RETURN
C
      WRITE(6,900) KDUM,JSTRIP,JMAT,INUM,JNUM,KCET,
     1 CEROID(KCET,1),CEROID(KCET,2),CEROID(KCET,3),IROW,ICOL
  900 FORMAT(10X,*KDUM   JSTRIP JMAT  INUM   JNUM*,2X,
     1            *KCET   CEROID(I,1),(I,2),(I,3) IROW  ICOL*/
     2         10X,6(I5,1X),5X,3(I6,2X),2(I5,1X))
      WRITE(6,901) NLOW,NHI,LALT,HALT,LH
```

```
501 FORMAT(10X,*NLOW   NHI   LALT   HALT   LH*/
   1       10X,5(I5,1X))
    RETURN
    END
```

```
      SUBROUTINE WRITCL(K)
C
C *** THIS SUBROUTINE WRITES RESULTS OF CLUSTERING   **
C *** LH - 1 IS LOWCEN, 2 IS HICEN                   **
C
      COMMON/LCENT/ LOWCEN(250,3),HICEN(250,3),KCET,NLOW,NHI,
     1   SMAX,LWRIT,LDEBG,JMAT,JSTRIP,LH
      COMMON/PCINT/ INITIAL(3),LAST(3),IPOINT(250),
     1 ISET(250),MSET(250),CEROID(250,3)
      INTEGER CEROID,HICEN
      DATA NEXT,NEXTL,NEXTH/1,1,1/
      NEXT = NEXTL
      IF(LH .EQ. 2) NEXT=NEXTH
      WRITE (6,900)
  900 FORMAT(///)
      IF(LH .EQ. 1) WRITE(6,901)
      IF(LH .EQ. 2) WRITE(6,902)
  901 FORMAT(//10X,*LOW ELEVATION CLUSTER*//)
  902 FORMAT(//10X,*HIGH ELEVATION CLUSTER*//)
      WRITE (6,903) NEXT,K
      WRITE (6,904) (IPOINT(I),I=1,K)
  903 FORMAT(5X,*CLUSTER NUMBER *,I4/
     1 5X,*TOTAL MEMBERS IN CLUSTER *,I3/)
  904 FORMAT(5X,*POINTERS TO CLUSTER MEMBER*/10(2X,I8))
      N1 = IPOINT(1)
      N2 = IPOINT(K)
      WRITE (6,905) (ISET(I),I=N1,N2)
      WRITE (6,906) NEXT,CEROID(KCET,2),CEROID(KCET,1),
     1              CEROID(KCET,3)
  905 FORMAT(/5X,*PACKED CLUSTER LOCATION ROW-COLUMN*/10(2X,I8))
  906 FORMAT( // 5X,*CENTER OF CLUSTER NUMBER *,I4/
     1       5X,*X-COORD*,I4,* Y-COORD*,I4,* Z-COORD*,I4///)
      NEXT = NEXT+1
      IF(LH .EQ. 1) NEXTL=NEXT
      IF(LH .EQ. 2) NEXTH=NEXT
      RETURN
      END
```

```
      SUBROUTINE LINKAGE
C
C *** LINKAGE ROUTINE                                    **
C *** IPOINT HAS LIST OF NEIGHBORHOOD POINTS             **
C *** NODE - NODE NUMBER OF POINT BEING EVALUATED        **
C *** NLOW - NUMBER OF POINTS IN LOWCEN                  **
C *** NHI  - NUMBER OF POINTS IN HICEN                   **
C *** LNEBR - POINTS IN NEIGHBORHOOD FOR LOWCEN          **
C *** KNEBR - POINTS IN NEIGHBORHOOD FOR HICEN           **
C
      COMMON/LCENT/ LOWCEN(250,3),HICEN(250,3),KCET,NLOW,NHI,
     1    SMAX,LWRIT,LDEBG,JMAT,JSTRIP,LH
      COMMON/POINT/ INITIAL(3),LAST(3),IPOINT(250)
      COMMON/SENVEH/ LALT,HALT,SENALT,VEHALT,IFREE,GRID,
     1 SWEA,SWNR,LTRS
      COMMON/SRAD/ RANGE,RE,MDIM,RATE,NSITE,ISITE(10,3),SYSR(10)
      COMMON/KINK/ LINK(250),LINKTO(1500,3),NBLKS,IC,
     1 IRADUS,LNEBR,KNEBR
      COMMON/DET/ DETLO(250),DETHI(250),FROM(250),TO(250,2)
      COMMON/EDGE/ DIST(100,2),IROW,JCOL,LSTR
      DIMENSION MPOINT(125),SR(10,3),NLIST(250)
      INTEGER HICEN,GRID,FROM,TO,SWEA,SWNR
      INTEGER EAST1,EAST2
      EQUIVALENCE (IPOINT(126),MPOINT(1))
      DATA IRADUS/15/
      DATA DETLO,DETHI/500*0/
      DATA SMAX,RTOD/100.0,57.2957795131/
C
      NBLKS = OLDB = 1
      IFREE = KFIRST = KLAST = 0
      LTOTAL = 0
C
C *** SORT LOWCEN AND HICEN   **
C
      CALL LHSORT(KFIRST,KLAST)
C
C *** DEVELOP NETWORK   **
C
      CALL RADIAL
      DO 10 I=1,250
      FROM(I) = 0
      TO(I,1) = 0
   10 TO(I,2) = 0
C
C *** CONSTRUCT ROUTE   **
C
   15 IC    = 1
      NODE  = KFIRST
      NEWPT = NODE
C
C *** FIND NEIGHBORHOOD ABOUT A LOW POINT   **
C
```

```
   20 IROW  = LOWCEN(NODE,1)
      JCOL  = LOWCEN(NODE,2)
      LOWCEN(NODE,1) = -(1000000+IROW)
      LOWCEN(NODE,2) = -(1000000+JCOL)
      CALL NEIGHB(NODE)
      CALL DIFFER(NODE)
C
   30 FROM(IC) = NEWPT
      IF(LWRIT .LE. 2) GO TO 35
      WRITE(6,921) NODE,JCOL,IROW,NEWPT,LPEN,IC
   35 XI = LAST(2)-JCOL
      YJ = LAST(1)-IROW
      KANG = RTOD*(ATAN2(YJ,XI))
      RANG = SQRT(XI**2 + YJ**2)
      DO 50 I=1,NSITE
      XI = ISITE(I,2)-JCOL
      YJ = ISITE(I,1)-IROW
      SR(I,1) = SQRT(XI**2 + YJ**2)
      IF((XI .EQ. 0.0) .OR. (SR(I,1) .EQ. 0)) GO TO 50
      SR(I,2) = RTOD*(ATAN2(YJ,XI))
      SR(I,3) = ABS(RTOD*(ATAN2(SYSR(I),SR(I,1))))
   50 CONTINUE
C
C ***      FIND MIN PENALTY VALUE                 **
C *** ANGLE HEADING IS MEASURED FROM X-AXIS       **
C *** IAK ANGLE IS MEASURED FROM HEADING          **
C *** THREE WEIGHTING SCHEMES                     **
C *** HEADING, RADAR AVOIDANCE, TERMINAL          **
C
      LPEN = 1000000
      LA   = LINK(IC)
      LB   = LINK(IC+1)-1
      IF(LB .LE. 0) LB=IFREE
      DO 200 LL=LA,LB
      NJ = LINKTO(LL,1)
      IF(NJ .LT. 0) GO TO 120
      IX = LOWCEN(NJ,2)
      JY = LOWCEN(NJ,1)
      GO TO 125
  120 IX = HICEN(-NJ,2)
      JY = HICEN(-NJ,1)
  125 XI = IX-JCOL
      YJ = JY-IROW
      RA = SQRT(XI**2 + YJ**2)
      IANG  = RTOD*(ATAN2(YJ,XI))
      IAK   = IANG-KANG
      IF(IAK .GT. 180) IAK=360-IAK
      IF(IAK .LT.-180) IAK=360+IAK
C
C *** HEADING WEIGHTING  **
C
      NWEIG = (IABS(IAK))/90+1
```

```
      IF(RANG .GT.RANGE) GO TO 130
C
C *** TERMINAL WEIGHTING  **
C
      NWEIG = 2*(IABS(IAK)/45)+1
      IF(RA .GT. RANG) NWEIG=100*NWEIG
      GO TO 150
C
C *** RADAR AVOIDANCE WEIGHTING  **
C
  130 IF(SYSR(1) .LE. 0.0) GO TO 150
      DO 135 I=1,NSITE
      ANG = IANG
      ANG = ABS(SR(I,2)-ANG)
      IF(ANG .GT. SR(I,3)) GO TO 135
      NWEIG = 2
      IF(RA .GT. (SR(I,1)-SYSR(I))) NWEIG=10
      GO TO 150
  135 CONTINUE
  150 NPEN  = NWEIG*LINKTO(LL,2)+NWEIG
      LINKTO(LL,3) = NPEN
C
      IF(LWRIT .LE. 2) GO TO 175
      WRITE(6,920) NODE,NJ,LA,LB,IC,IFREE,RANGE,RANG,RA
      WRITE(6,924) IAK,IANG,KANG,NWEIG,LPEN,NPEN,XI,YJ
  175 IF(NPEN .GE. LPEN) GO TO 200
      LPEN  = NPEN
      NEWPT = LINKTO(LL,1)
  200 CONTINUE
C
      IF(LWRIT .GT. 2) WRITE(6,921) NODE,JCOL,IROW,NEWPT,LPEN,IC
      IF(NEWPT .EQ. KLAST)   GO TO 475
      NODE       = NEWPT
      TC(IC,1) = NEWPT
      TC(IC,2) = LPEN
      IC         = IC+1
      LTOTAL     = LTOTAL+LPEN
      IF(IC     .GE. 1950) CALL RITE
      IF(IFREE  .GE. 1800) CALL RITE
      IF(NODE   .LT. 0)    GO TO 400
      GO TO 20
C
C *** FIND NEIGHBORHOOD ABOUT A HIGH POINT  **
C
  400 NODE = -NEWPT
      IROW = HICEN(NODE,1)
      JCOL = HICEN(NODE,2)
      HICEN(NODE,1) = -(1000000+IROW)
      HICEN(NODE,2) = -(1000000+JCOL)
      CALL NEIGHB(NODE)
      CALL DIFFER(NODE)
      GO TO 30
```

```
  450 IF(IFLAG .EQ. -1) GO TO 475
      IFLAG  =-1
      IRADUS = 2*IRADUS
      GO TO 15
  475 TO(IC,1) = NEWPT
      TO(IC,2) = LPEN
C
C *** CHECK FOR DATA BLOCKS WRITTEN TO WORKING STORAGE  **
C
      IF(NBLKS .GT. 1) GO TO 700
C
C *** REMOVE LARGE NEGATIVE VALUE FROM ROUTE NODES  **
C
  480 DO 500 I=1,IC
      NN = FROM(I)
      IF(NN .LT. 0) GO TO 485
      LOWCEN(NN,1) = -(LOWCEN(NN,1)+1000000)
      LOWCEN(NN,2) = -(LOWCEN(NN,2)+1000000)
      GO TO 500
  485 NN = -NN
      HICEN(NN,1)  = -(HICEN(NN,1) +1000000)
      HICEN(NN,2)  = -(HICEN(NN,2) +1000000)
  500 CONTINUE
C
C *** WRITE NODE POINTS OF THE ROUTE  **
C
      LL = 0
      WRITE(6,910)
      DO 650 I=1,IC
      LL = LL+1
      NOD1 = FROM(I)
      NOD2 = TO(I,1)
      IF(NOD1 .LT. 0) GO TO 550
      NORTH1 = GRID*LOWCEN(NOD1,1)+SWNR
      EAST1  = GRID*LOWCEN(NOD1,2)+SWEA
      IF(NOD2 .LT. 0) GO TO 575
  525 NORTH2 = GRID*LOWCEN(NOD2,1)+SWNR
      EAST2  = GRID*LOWCEN(NOD2,2)+SWEA
      GO TO 600
  550 NOD1 = -NOD1
      NORTH1 = GRID*HICEN(NOD1,1)+SWNR
      EAST1  = GRID*HICEN(NOD1,2)+SWEA
      IF(NOD2 .GT. 0) GO TO 525
  575 NOD2 = -NOD2
      NORTH2 = GRID*HICEN(NOD2,1)+SWNR
      EAST2  = GRID*HICEN(NOD2,2)+SWEA
  600 WRITE(6,911) FROM(I),EAST1,NORTH1,TO(I,1),
     1             TO(I,2),EAST2,NORTH2
      IF(LL .LE. 25) GO TO 650
      WRITE(6,910)
      LL = 0
  650 CONTINUE
```

```
      WRITE(6,912) LTRS,SWEA,SWNR,LTOTAL
      CALL WRLINK
      ICK  = IC-1
      LA   = 0
      K    = 1
      DO 800 I=1,ICK
      IF(K .GE. IC) GO TO 850
      LA   = LA+1
      NJ   = FROM(K)
      NN   = TO(K,1)
      NLIST(LA) = NJ
      IF(NJ .LT. 0) GO TO 670
      JCOL = LOWCEN(NJ,2)
      IROW = LOWCEN(NJ,1)
      GO TO 675
  670 JCOL = HICEN(-NJ,2)
      IROW = HICEN(-NJ,1)
  675 IF(NN .LT. 0) GO TO 680
      IX   = LOWCEN(NN,2)
      JY   = LOWCEN(NN,1)
      GO TO 685
  680 IX   = HICEN(-NN,2)
      JY   = HICEN(-NN,1)
  685 XI   = IX-JCOL
      YJ   = JY-IROW
      DISA = SQRT(XI**2 + YJ**2)
      K    = K+1
      LL   = K
      DO 800 J=LL,IC
      NJ   = TO(J,1)
      IF(NJ .LT. 0) GO TO 690
      IX   = LOWCEN(NJ,2)
      JY   = LOWCEN(NJ,1)
      GO TO 695
  690 IX   = HICEN(-NJ,2)
      JY   = HICEN(-NJ,1)
  695 XI   = IX-JCOL
      YJ   = JY-IROW
      DISB = SQRT(XI**2 + YJ**2)
      IF(DISB .GT. DISA) GO TO 800
      K    = J+1
      DISA = DISB
  800 CONTINUE
      I    = ICK+1
      LA   = LA+1
      NLIST(LA) = FROM(I)
  850 CONTINUE
      NLIST(LA+1) = TO(IC,1)
      WRITE(6,915)
      DO 875 J=1,LA
  875 WRITE(6,916) NLIST(J),NLIST(J+1)
C
```

```
      IF(NBLKS .LT. CLCB) GO TO 710
      RETURN
  700 CALL RITE
      OLDB = NBLKS-1
      REWIND 9
  710 READ(9) NBLKS,IFREE,IC
      READ(9) (FROM(I),I=1,IC)
      READ(9) ((TO(I,J),J=1,2),I=1,IC)
      READ(9) (LINK(I),I=1,IC)
      READ(9) ((LINKTO(I,J),J=1,3),I=1,IFREE)
      GO TO 480
C
  910 FORMAT(1H1//////30X,*TABLE      NODE LINKAGE FOR ROUTE*//
     1 19X,*FROM*,4X,*EASTING*,2X,*NORTHING*,
     2 6X,*TO*,4X,*PENALTY*,3X,*EASTING*,2X,*NORTHING*/)
  911 FORMAT(18X,I5,2X,2(I9,1X),2X,I5,2X,3(I9,1X))
  912 FORMAT( //19X,*SOUTHWEST CORNER *,A2,2I4//
     1 110X,*TOTAL PENALTY*/110X,*RUNNING TOTAL*/110X,I12)
  915 FORMAT(1H1//////30X,*TABLE      MODIFIED ROUTE*//
     1 37X,*FROM*,5X,*TO*/)
  916 FORMAT(36X,I5,2X,I5)
  920 FORMAT(/6X,*NODE  NJ   LA  LB  IC  IFREE RANGE*,
     1 6X,*RANG   RA*/5X,6(I4,1X),3(F8.3,1X))
  921 FORMAT(10X,*NODE X-CRD Y-CRD*/10X,3(I4,1X)/10X,*NEWPT*,
     1          2X,*LPEN      IC*/10X,I4,1X,I10,1X,I4)
  924 FORMAT( 8X,*IAK IANG  KANG  NWEIG      LPEN*,
     1  7X,*NPEN*, 5X,*XI*,10X,*YJ*/
     1 5X,I5,1X,I5,1X,I5,1X,I5,1X,I10,1X,I10,2(F10.4,1X))
      END
```

```
      SUBROUTINE LHSORT(KFIRST,KLAST)
C
C *** THIS SUBROUTINE SORTS LOWCEN AND HICEN   **
C *** IN ASCENDING ORDER BY ROWS               **
C
      COMMON/LCENT/ LOWCEN(250,3),HICEN(250,3),KCET,NLOW,NHI,
     1   SMAX,LWRIT,LDEBG,JMAT,JSTRIP,LH
      COMMON/POINT/ INITIAL(3),LAST(3),IPOINT(250)
      INTEGER HICEN
C
      NLOW = NLOW+1
      LOWCEN(NLOW,1) = INITIAL(1)
      LOWCEN(NLOW,2) =-INITIAL(2)*LAST(2)
      LOWCEN(NLOW,3) = INITIAL(3)
      NLOW = NLOW+1
      LOWCEN(NLOW,1) = LAST(1)
      LOWCEN(NLOW,2) =-LAST(2)
      LOWCEN(NLOW,3) = LAST(3)
C
C *** LOWCEN  **
C
      KK = NLOW-1
      DO 10 J=1,KK
      JJ = J+1
      DO 10 I=JJ,NLOW
      IF(LOWCEN(J,1) .LE. LOWCEN(I,1)) GO TO 10
      IS1 = LOWCEN(J,1)
      IS2 = LOWCEN(J,2)
      IS3 = LOWCEN(J,3)
      LOWCEN(J,1) = LOWCEN(I,1)
      LOWCEN(J,2) = LOWCEN(I,2)
      LOWCEN(J,3) = LOWCEN(I,3)
      LOWCEN(I,1) = IS1
      LOWCEN(I,2) = IS2
      LOWCEN(I,3) = IS3
   10 CONTINUE
C
      IS2 = -INITIAL(2)*LAST(2)
      DO 15 I=1,NLOW
      IF(LOWCEN(I,2) .GT. 0) GO TO 15
      IF(LOWCEN(I,2) .EQ.  IS2)    KFIRST=I
      IF(LOWCEN(I,2) .EQ. -LAST(2)) KLAST=I
   15 CONTINUE
      WRITE(6,907) INITIAL(2),LAST(2),IS2,LOWCEN(KFIRST,2),
     1 LOWCEN(KLAST,2),KFIRST,KLAST
  907 FORMAT(/ 2X,*INITIAL*,2X,*LAST*,4X,*IS2*,6X,*LOWCEN-1*,
     1 2X,*LOWCEN-L*,2X,*KFIRST*,3X,*KLAST*/2X,7(I6,2X))
      LOWCEN(KFIRST,2) = INITIAL(2)
      LOWCEN(KLAST,2)  = LAST(2)
      WRITE(6,906)
      WRITE(6,900)
      KL = 0
```

```
      DO 20 I=1,NLOW,10
      KK = I-1+10
      IF(KK .GT. NLOW) KK=NLOW
      KL = KL+1
      WRITE(6,901) (LOWCEN(J,2),J=I,KK)
      WRITE(6,902) (LOWCEN(J,1),J=I,KK)
      WRITE(6,903) (LOWCEN(J,3),J=I,KK)
      IF(KL .LE. 7) GO TO 20
      WRITE(6,906)
      WRITE(6,900)
      KL = 0
   20 CONTINUE
      WRITE(6,904) NLOW
C
C *** HICEN  **
C
      KK = NHI-1
      DO 30 J=1,KK
      JJ = J+1
      DO 30 I=JJ,NHI
      IF(HICEN(J,1) .LE. HICEN(I,1)) GO TO 30
      IS1 = HICEN(J,1)
      IS2 = HICEN(J,2)
      IS3 = HICEN(J,3)
      HICEN(J,1) = HICEN(I,1)
      HICEN(J,2) = HICEN(I,2)
      HICEN(J,3) = HICEN(I,3)
      HICEN(I,1) = IS1
      HICEN(I,2) = IS2
      HICEN(I,3) = IS3
   30 CONTINUE
C
      WRITE(6,906)
      WRITE(6,905)
      KL = 0
      DO 40 I=1,NHI,10
      KK = I-1+10
      IF(KK .GT. NHI) KK=NHI
      KL = KL+1
      WRITE(6,901) (HICEN(J,2),J=I,KK)
      WRITE(6,902) (HICEN(J,1),J=I,KK)
      WRITE(6,903) (HICEN(J,3),J=I,KK)
      IF(KL .LE. 7) GO TO 40
      WRITE(6,906)
      WRITE(6,905)
      KL = 0
   40 CONTINUE
      WRITE(6,904) NHI
      WRITE(6,906)
C
  900 FORMAT(//////40X,*TABLE      LOW ELEVATION NODE POINTS*//)
  901 FORMAT(18X,*X-COORDINATE *,10I7)
```

```
902 FORMAT(18X,*Y-COORDINATE *,10I7)
903 FORMAT(18X,*Z-COORDINATE *,10I7/)
904 FORMAT(//18X,*NUMBER OF NODES *,I5)
905 FORMAT(///////40X,*TABLE       HIGH ELEVATION NODE POINTS*//)
906 FORMAT(1H1)
    RETURN
    END
```

```
      SUBROUTINE NEIGHB(NODE)
C
C *** IROW IS ROW INDEX (Y-COORD) BEING EVALUATED   **
C *** JCOL IS COLUMN INDEX (X-COORD)                 **
C *** NODE LOCATION CURRENTLY BEING PROCESSED        **
C
      COMMON/LCENT/ LOWCEN(250,3),HICEN(250,3),KCET,NLOW,NHI,
     1   SMAX,LWRIT,LDEBG,JMAT,JSTRIP,LH
      COMMON/POINT/ INITIAL(3),LAST(3),IPOINT(250)
      COMMON/SENVEH/ LALT,HALT,SENALT,VEHALT,IFREE,GRID,
     1 SWEA,SWNR,LTRS
      COMMON/KINK/ LINK(250),LINKTO(1500,3),NBLKS,IC,
     1 IRADUS,LNEBR,KNEBR
      COMMON/EDGE/ DIST(100,2),IROW,JCOL,LSTR
      DIMENSION MPOINT(125)
      INTEGER HICEN
      EQUIVALENCE (IPOINT(126),MPOINT(1))
C
      IRAD = IRADUS
   10 LA   = IROW-IRAD
      IF(LA .LE. 0) LA=1
      LB   = IROW+IRAD
C
C *** IBEG IS THE INDEX VALUE WHERE LA = ROW NUMBER         **
C *** IEND IS THE INDEX VALUE WHERE LB+1 = ROW #            **
C *** IPOINT HAS INDEX VALUE OF LOWCEN FOR NEIGHBORHOOD     **
C *** THIS RESTRICTS THE SEARCH TO ONLY THOSE ROWS          **
C *** THAT ARE NEAR THE "NODE"                              **
C
      DO 100 I=1,NLOW
      NROW = LOWCEN(I,1)
      IF(NROW .LT. LA) GO TO 100
      IBEG = I
      GO TO 101
  100 CONTINUE
  101 DO 102 I=IBEG,NLOW
      NROW = LOWCEN(I,1)
      IF(NROW .LT. LB) GO TO 102
      IEND = I
      GO TO 103
  102 CONTINUE
C
C *** FIND THE NEIGHBORHOOD OF LOW ELEVATION POINTS   **
C
  103 LNEBR = 0
      DO 104 I=IBEG,IEND
      IF(LOWCEN(I,1) .LT.-1000000) GO TO 104
      LDIFF = IABS(LOWCEN(I,1)-IROW)
      IF(LDIFF .GT. IRAD) GO TO 104
      LDIFF = IABS(LOWCEN(I,2)-JCOL)
      IF(LDIFF .GT. IRAD) GO TO 104
      LNEBR = LNEBR+1
```

```
      IF(LNEBR .EQ. 100) GO TO 400
      IPOINT(LNEBR) = I
  104 CONTINUE
      IF(LNEBR .EQ. 0)   GO TO 300
  125 IFLAG = 0
      DO 200 I=1,NHI
      NROW = HICEN(I,1)
      IF(NROW .LT. LA)   GO TO 200
      IBEG = I
      GO TO 201
  200 CONTINUE
  201 DO 202 I=IBEG,NHI
      NROW = HICEN(I,1)
      IF(NROW .LT. LB)   GO TO 202
      IEND = I
      GO TO 203
  202 CONTINUE
C
C *** FIND THE NEIGHBORHOOD OF HIGH ELEVATION POINTS  **
C
  203 KNEBR = 0
      DO 204 I=IBEG,IEND
      IF(HICEN(I,1) .LT.-1000000) GO TO 204
      LDIFF = IABS (HICEN(I,1)-IROW)
      IF(LDIFF .GT. IRAD) GO TO 204
      LDIFF = IABS (HICEN(I,2)-JCOL)
      IF(LDIFF .GT. IRAD) GO TO 204
      KNEBR = KNEBR+1
      IF(KNEBR .GT. 100) GO TO 500
      MPOINT(KNEBR) = I
  204 CONTINUE
      IF(LWRIT .LE. 2) RETURN
      WRITE(6,900) NODE,JCOL,IROW
      DO 275 N1=1,LNEBR
      N2 = IPOINT(N1)
  275 WRITE(6,901) N1,N2,LOWCEN(N2,2),LOWCEN(N2,1),LOWCEN(N2,3)
      WRITE(6,902)
      DO 285 N1=1,KNEBR
      N2 = MPOINT(N1)
  285 WRITE(6,901) N1,N2,HICEN(N2,2),HICEN(N2,1),HICEN(N2,3)
C
  900 FORMAT(/6X,* PRIMARY NODE *,I4,I5,*,X-COORD *,
     1 I5,*,Y-COORD*/10X,*LOW POINTS*)
  901 FORMAT(10X,*NEIGHB - *,I3,* NODE *,I3,*.*,I5,
     1 *,X-COORD *,I5,*,Y-COORD*,I5,*,Z-COORD*)
  902 FORMAT(10X,*HIGH POINTS*)
      RETURN
C
C *** THIS ENSURES THAT AT LEAST ONE POINT BUT NOT MORE  **
C *** THAN 100 POINTS ARE FOUND                           **
C
  300 IRAD = 2*IRAD
```

AD-A091 793 ARMY MISSILE COMMAND REDSTONE ARSENAL AL PLANS ANAL--ETC F/G 15/3
A HEURISTIC ROUTE SELECTION MODEL FOR LOW LEVEL AIRCRAFT FLIGHT--ETC(U)
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3 - 3

END
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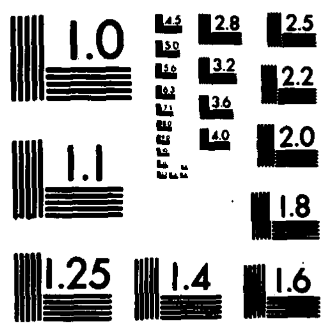

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

```
      IF(IRAD .GT. 999999) RETURN
      GC TO 10
  400 IRAD = IRAD/2
      IF(IRAD .EQ. C) GO TC 450
      GO TO 10
  450 LNEBR = 100
      GO TO 125
  500 IF(IFLAG .EQ. 1) GO TO 600
      IRAD = IRAD/2
      IFLAG = 1
      GO TC 203
  600 KNEBR = 100
      RETURN
      END
```

```
      SUBROUTINE DIFFER(NODE)
C
C *** THIS SUBROUTINE FINDS RANGE OF HEIGHT AND DISTANCE  **
C *** DIST(I,1) = THE PLANAR DIST TO POINT FOR LOWCEN     **
C *** DIST(I,2) = THE PLANAR DIST TO POINT FOR HICEN      **
C *** DMIN = MIN DIST BETWEEN NODE AND ADJACENT POINTS    **
C *** DMAX = MAX DIST BETWEEN NODE AND ADJACENT POINTS    **
C *** KZMIN = MIN ELEVATION BETWEEN NODE AND ADJ PTS      **
C *** KZMAX = MAX ELEVATION BETWEEN NODE AND ADJ PTS      **
C
      COMMON/LCENT/ LOWCEN(250,3),HICEN(250,3),KCET,NLOW,NHI,
     1   SMAX,LWRIT,LDEBG,JMAT,JSTRIP,LH
      COMMON/POINT/ INITIAL(3),LAST(3),IPOINT(250)
      COMMON/SENVEH/ LALT,HALT,SENALT,VEHALT,IFREE,GRID,
     1 SWEA,SWNR,LTRS
      COMMON/KINK/ LINK(250),LINKTO(1500,3),NBLKS,IC,
     1 IRADUS,LNEBR,KNEBR
      COMMON/DET/ DETLO(250),DETHI(250),FROM(250),TO(250,2)
      COMMON/EDGE/ DIST(100,2),IROW,JCOL,LSTR
      DIMENSION MPOINT(125)
      INTEGER HICEN
      EQUIVALENCE (IPOINT(126),MPOINT(1))
      DATA RTOD,LSTR/57.2957795131,1/
C
C *** INITIALIZE VARIABLES  **
C
      DO 10 I=1,100
      DIST(I,1) = 0.0
   10 DIST(I,2) = 0.0
      DMIN  = 1000000
      DMAX  =-1000000
      KZMIN = 1000000
      KZMAX =-1000000
C
C *** PROCESS LOWCEN
C
      DO 130 I=1,LNEBR
      J   = IPOINT(I)
      YJ  = LOWCEN(J,1)-IROW
      XI  = LOWCEN(J,2)-JCOL
      KZI = LOWCEN(J,3)
      IF(KZI .GE. KZMIN) GO TO 15
      KZMIN = KZI
   15 IF(KZI .LE. KZMAX) GO TO 20
      KZMAX = KZI
   20 CONTINUE
      DIST(I,1) = SQRT(XI**2+YJ**2)
      IF(DIST(I,1) .GE. DMIN) GO TO 120
      DMIN = DIST(I,1)
  120 IF(DIST(I,1) .LE. DMAX) GO TO 130
      DMAX = DIST(I,1)
  130 CONTINUE
```

```
C
C *** PROCESS HICEN  **
C
      DO 150 I=1,KNEBR
      J   = MPOINT(I)
      YJ  = HICEN(J,1)-IROW
      XI  = HICEN(J,2)-JCOL
      KZI = HICEN(J,3)
      IF(KZI .GE. KZMIN) GO TO 35
      KZMIN = KZI
      GO TO 45
   35 IF(KZI .LE. KZMAX) GO TO 45
      KZMAX = KZI
   45 CONTINUE
      DIST(I,2) = SQRT(XI**2+YJ**2)
      IF(DIST(I,2) .GE. DMIN) GO TO 140
      DMIN = DIST(I,2)
      GO TO 150
  140 IF(DIST(I,2) .LE. DMAX) GO TO 150
      DMAX = DIST(I,2)
  150 CONTINUE
      IF(LWRIT .LE. 2) GO TO 75
      WRITE(6,900) NODE,JCOL,IROW,LNEBR
      DO 50 LA=1,LNEBR,10
      LB = LA-1+10
      IF(LB .GT. LNEBR) LB=LNEBR
   50 WRITE(6,901) (DIST(I,1),I=LA,LB)
      WRITE(6,900) NODE,JCOL,IROW,KNEBR
      DO 60 LA=1,KNEBR,10
      LB = LA-1+10
      IF(LB .GT. KNEBR) LB=KNEBR
   60 WRITE(6,902) (DIST(I,2),I=LA,LB)
C
C *** SORT IN INCREASING ORDER  **
C
   75 IF(LNEBR .EQ. 1) GO TO 85
      KK = LNEBR-1
      DO 250 J=1,KK
      JJ = J+1
      DO 250 I=JJ,LNEBR
      IF(DIST(J,1) .LE. DIST(I,1)) GO TO 250
      SA1 = DIST(J,1)
      JSA = IPOINT(J)
      DIST(J,1) = DIST(I,1)
      IPOINT(J) = IPOINT(I)
      DIST(I,1) = SA1
      IPOINT(I) = JSA
  250 CONTINUE
   85 IF(KNEBR .EQ. 1) GO TO 300
      KK = KNEBR-1
      DO 275 J=1,KK
      JJ = J+1
```

```
      DO 275 I=JJ,KNEBR
      IF(DIST(J,2) .LE. DIST(I,2)) GO TO 275
      SA1 = DIST(J,2)
      JSA = MPOINT(J)
      DIST(J,2) = DIST(I,2)
      MPOINT(J) = MPOINT(I)
      DIST(I,2) = SA1
      MPOINT(I) = JSA
  275 CONTINUE
      IF(LWRIT .LE. 2) GO TO 300
      WRITE(6,903) DMIN,DMAX,KZMIN,KZMAX
      WRITE(6,900) NODE,JCOL,IROW,LNEBR
      DO 90 LA=1,LNEBR,10
      LB = LA-1+10
      IF(LB .GT. LNEBR) LB=LNEBR
   90 WRITE(6,901) (DIST(I,1),I=LA,LB)
      WRITE(6,900) NODE,JCOL,IROW,KNEBR
      DO 95 LA=1,KNEBR,10
      LB = LA-1+10
      IF(LB .GT. KNEBR) LB=KNEBR
   95 WRITE(6,902) (DIST(I,2),I=LA,LB)
C
C *** CALCULATE PENALTY VALUE FOR POINTS  **
C
  300 DRANG = DMAX-DMIN
      IF(DRANG .GT. 0.0) DRANG=1.0/DRANG
      ZRANG = KZMAX-KZMIN+1
      IF(ZRANG .GT. 0.0) ZRANG=1.0/ZRANG
      DO 320 I=1,LNEBR
      IFREE = IFREE+1
      IJ = IPOINT(I)
      LINKTO(IFREE,1) = IJ
      XYZ = LOWCEN(IJ,3)-KZMIN
      XYZ = DETLC(IJ)+XYZ*ZRANG
  320 LINKTO(IFREE,2) = 100.0*(XYZ+1-(DIST(I,1)-DMIN)*DRANG)
      DO 325 I=1,KNEBR
      IFREE = IFREE+1
      IJ = MPOINT(I)
      LINKTO(IFREE,1) = -IJ
      XYZ = HICEN(IJ,3)-KZMIN
      XYZ = DETHI(IJ)+XYZ*ZRANG
  325 LINKTO(IFREE,2) = 100.0*(XYZ+1-(DIST(I,2)-DMIN)*DRANG)
      LINK(IC) = LSTR
      LSTR = IFREE+1
C
  900 FORMAT(/ 5X,*FROM DIFFER* / 5X,*NODE *,I4,I5,*,X-COORD *,
     1 I5,*,Y-COORD *,I5,* LINKS*)
  901 FORMAT( 5X,*DISTANCE LOW  *,10(1X,F10.3))
  902 FORMAT( 5X,*DISTANCE HIGH *,10(1X,F10.3)/)
  903 FORMAT(11X,*DMIN*,8X,*DMAX  KZMIN  KZMAX*/
     1 5X,2(F10.4,2X),I4,2X,I4)
      RETURN
      END
```

```
      SUBROUTINE RITE
C
C *** THIS SUBROUTINE SAVES ARRAYS IN WORKING STORAGE  **
C
      COMMON/SENVEH/ LALT,HALT,SENALT,VEHALT,IFREE,GRID,
     1 SWEA,SWNR,LTPS
      COMMON/KINK/ LINK(250),LINKTO(1500,3),NBLKS,IC,
     1 IRADUS,LNEBR,KNEBR
      COMMON/DET/ DETLO(250),DETHI(250),FROM(250),TO(250,2)
      COMMON/EDGE/ DIST(100,2),IROW,JCOL,LSTR
      INTEGER FROM,TO
C *** BINARY UNFORMATTED TAPE  **
      WRITE(9) NBLKS,IFREE,IC
      WRITE(9) (FROM(I),I=1,IC)
      WRITE(9) ((TO(I,J),J=1,2),I=1,IC)
      WRITE(9) (LINK(I),I=1,IC)
      WRITE(9) ((LINKTO(I,J),J=1,3),I=1,IFREE)
      IFREE = IC = LSTR = 1
      NBLKS = NBLKS+1
      RETURN
      END
```

```
      SUBROUTINE WRLINK
C
C *** THIS SUB' WRITES THE LINKAGE THAT'S BEEN DEVELOPED  **
C
      COMMON/LCENT/ LOWCEN(250,3),HICEN(250,3),KCET,NLOW,NHI,
     1   SMAX,LWRIT,LDEBG,JMAT,JSTRIP,LH
      COMMON/POINT/ INITIAL(3),LAST(3),IPOINT(250)
      COMMON/SENVEH/ LALT,HALT,SENALT,VEHALT,IFREE,GRID,
     1 SWEA,SWNR,LTRS
      COMMON/KINK/ LINK(250),LINKTO(1500,3),NBLKS,IC,
     1 IRADUS,LNEBR,KNEBR
      COMMON/DET/ DETLO(250),DETHI(250),FROM(250),TO(250,2)
      INTEGER HICEN,FROM,TO
      WRITE(6,900)
  900 FORMAT(1H1 /10X,*NODE LINKAGE OUTPUT*)
      WRITE(6,901) IFREE,NBLKS,NLOW,IRADUS
  901 FORMAT(10X,*IFREE  NBLKS      NLOW   IRADUS*/
     1 10X,4(I6,1X))
      NM = IFREE+1
      DO 15 NA=1,NM,10
      NB = NA-1+10
   15 WRITE(6,902) (LINKTO(I,1),I=NA,NB),(LINKTO(I,2),I=NA,NB),
     1              (LINKTO(I,3),I=NA,NB)
  902 FORMAT(10X,*LINKTO(I,1)  *,10(2X,I6)/
     1        10X,*LINKTO(I,2)  *,10(2X,I6)/
     2        10X,*LINKTO(I,3)  *,10(2X,I6)/)
      WRITE(6,903)
  903 FORMAT(1H1)
      WRITE(6,904)
      DO 10 J=1,IC,10
      JJ = J-1+10
      IF(JJ .GT. IC) JJ=IC
   10 WRITE(6,905) (LINK(I),I=J,JJ)
  904 FORMAT(/10X,*LINKAGE POINTERS*/)
  905 FORMAT(10X,10(I6,2X))
      KC = 0
      DO 20 NJ=1,IC
      IF(KC .EQ. 0) WRITE(6,906)
      KC = KC+1
      NN = FROM(NJ)
      J  = LINK(NJ)
      JJ = LINK(NJ+1)-1
      IF(JJ .LT. 0) JJ=IFREE
      JJJ= JJ-J+1
      WRITE(6,907) NN,JJJ
      IF(NN .GT. 0) WRITE(6,908)  LOWCEN(NN,2),
     1                 LOWCEN(NN,1),LOWCEN(NN,3)
      IF(NN .LT. 0) WRITE(6,908)  HICEN(-NN,2),
     1                 HICEN(-NN,1),HICEN(-NN,3)
      WRITE(6,909) (LINKTO(I,1),I=J,JJ)
      WRITE(6,910) (LINKTO(I,2),I=J,JJ)
      WRITE(6,911) (LINKTO(I,3),I=J,JJ)
```

```
      IF(KC .LE. 5) GC TO 20
      KC = 0
   20 CONTINUE
C
  906 FORMAT(1H1///////34X,*NODE LINKAGE*)
  907 FORMAT(/20X,*NODE NO.*,I5,* TOTAL LINKS *,I4)
  908 FORMAT(20X,*X,Y,Z COORDINATE *,I4,1H, ,1X,I4,1H, ,1X,I4)
  909 FORMAT(20X,*LINKED TO *,10I7)
  910 FORMAT(20X,*EXPOSURE  *,10I7)
  911 FORMAT(20X,*WEIGHTED  *,10I7)
      RETURN
      END
```

```
      SUBROUTINE SAVE
C
C *** THIS ROUTINE IS USED TO WRITE VALUES OUT FOR PLOTTING  **
C
      COMMON/LCENT/ LOWCEN(250,3),HICEN(250,3),KCET,NLOW,NHI,
     1    SMAX,LWRIT,LDEBG,JMAT,JSTRIP,LH
      COMMON/SENVEH/ LALT,HALT,SENALT,VEHALT,IFREE,GRID,
     1 SWEA,SWNR,LTRS
      COMMON/KINK/ LINK(250),LINKTO(1500,3),NBLKS,IC,
     1 IRADUS,LNEBR,KNEBR
      COMMON/DET/ DETLO(250),DETHI(250),FROM(250),TO(250,2)
      INTEGER HICEN,FROM,TO
C
      WRITE(7,900) NLOW,NHI,IC,IFREE
      WRITE(7,901) ((LOWCEN(I,J),J=1,3),I=1,NLOW)
      WRITE(7,901) ((HICEN(I,J),J=1,3),I=1,NHI)
      WRITE(7,902) (DETLO(I),I=1,NLOW)
      WRITE(7,902) (DETHI(I),I=1,NHI)
      WRITE(7,901) (FROM(I),I=1,IC)
      WRITE(7,901) ((TO(I,J),J=1,2),I=1,IC)
      WRITE(7,901) (LINK(I),I=1,IC)
      WRITE(7,901) ((LINKTO(I,J),J=1,3),I=1,IFREE)
  900 FORMAT(4I10)
  901 FORMAT(10(I9,1X))
  902 FORMAT(10F10.3)
      RETURN
      END
```

```
      SUBROUTINE RADIAL
C
C *** THIS ROUTINE CALCULATES THE LINE OF SIGHT (LOS)      **
C *** BETWEEN NODE POINT AND SENSORS. LOS IS THE           **
C *** INTERVISIBILITY BETWEEN PTS.  ONCE ANY TERRAIN       **
C *** MASKING POINT IS FOUND PROCESSING OF THAT NODE-      **
C *** SENSOR COMBINATION IS FINISHED.                     L**
C
      COMMON/IDAT/  KMAT,ISTRIP,IDATA(15,15,10)
      COMMON/LCENT/ LOWCEN(250,3),HICEN(250,3),KCET,NLOW,NHI,
     1   SMAX,LWRIT,LDEBG,JMAT,JSTRIP,LH
      COMMON/POINT/ INITIAL(3),LAST(3),IPOINT(250)
      COMMON/SENVEH/ LALT,HALT,SENALT,VEHALT,IFREE,GRID,
     1 SWEA,SWNR,LTRS
      COMMON/SRAD/ RANGE,RE,MDIM,RATE,NSITE,ISITE(10,3),SYSR(10)
      COMMON/DET/ DETLO(250),DETHI(250),DISLO(250),
     1 DISHI(250),XX(250)
      DIMENSION IFINISH(250)
      INTEGER SENALT,VEHALT,HICEN,EAST,WEST,SOUTH,GRID
      LOGICAL ZCURVE,ZNORTH,ZSOUTH
      EQUIVALENCE (RMAX,DIS)
      DATA RE,SRTWH,RATE/8490200.0,0.7071068,1.0/
      DATA SENALT,VEHALT,MDIM/3,10,15/
C
C ***     INITIALIZE     **
C
      REWIND 8
      ZCURVE= RE.GT.0.0
      ZGRID = GRID
      RE     = RE/ZGRID
      DZ     = 0.0
C *** AREA LIMITS  **
      NORTH = KMAT*MDIM
      SOUTH = 1
C
      DO 2400 JK=1,ISTRIP
      JSTRIP = JK
      EAST = JSTRIP*MDIM
      WEST = (JSTRIP-1)*MDIM+1
      CALL INDATA
      LH = 1
      ILOOP = NLOW
      DO 2400 KLN=1,2
C
      DO 2000 KK=1,NSITE
      KSIT = ISITE(KK,2)
      YSIT = ISITE(KK,1)
      ZSIT = ISITE(KK,3)+SENALT
C
      DO 2000 LP=1,ILOOP
C *** TEST IFINISH FOR COMPLETION  **
      IEXP = (LH-1)*10+KK-1
```

```
      IFIN = AND(IFINISH(LP),2**(IEXP))
      IF(IFIN .NE. 0) GO TO 2000
      IF(LH .EQ. 2) GO TO 400
C
      KS1 = LOWCEN(LP,2)
      IF    (((KS1.GT.EAST) .AND. (KSIT.GT.EAST))
     1  .OR.((KS1.LT.WEST) .AND. (KSIT.LT.WEST))) GO TO 2000
C
C *** DETERMINE WESTERN MOST POINT OF PAIR  **
      IF((KSIT-KS1) .GE. 0) GO TO 300
C
C *** SWAP SENSOR AND NODE  **
C
      XP  = KS1
      YP  = LOWCEN(LP,1)
      ZP  = LOWCEN(LP,3)+VEHALT
      KS1 = KSIT
      XS1 = KSIT
      YS1 = YSIT
      ZS1 = ZSIT
      GO TO 525
C
  300 XS1 = KS1
      YS1 = LOWCEN(LP,1)
      ZS1 = LOWCEN(LP,3)+VEHALT
      XP  = KSIT
      YP  = YSIT
      ZP  = ZSIT
      GO TO 525
C
  400 KS1 = HICEN(LP,2)
      IF    (((KS1.GT.EAST) .AND. (KSIT.GT.EAST))
     1  .OR.((KS1.LT.WEST) .AND. (KSIT.LT.WEST))) GO TO 2000
C
C *** DETERMINE WESTERN MOST POINT OF PAIR  **
      IF((KSIT-KS1) .GE. 0) GO TO 410
C
C *** SWAP SENSOR AND NODE  **
C
      XP  = KS1
      YP  = HICEN(LP,1)
      ZP  = HICEN(LP,3)+VEHALT
      KS1 = KSIT
      XS1 = KSIT
      YS1 = YSIT
      ZS1 = ZSIT
      GO TO 525
C
  410 XS1 = KS1
      YS1 = HICEN(LP,1)
      ZS1 = HICEN(LP,3)+VEHALT
      XP  = KSIT
```

```
      YP   = YSIT
      ZP   = ZSIT
C
C *** CALCULATE TANGENT AND DISTANCE BETWEEN SENSOR/NODE    **
C *** THE AZIMUTH ANGLE IS MEASURED FROM NORTH CLOCKWISE    **
C
  525 XSP = XP-XS1
      YSP = YP-YS1
      ZSP = ZP-ZS1
      DIS = SQRT(XSP**2 + YSP**2)
      IF(ZCURVE) DZ=0.5*DIS*(DIS/RE)
      TM   = (ZSP-DZ)/(DIS*ZGRID)
      XSIN = XSP/DIS
      YCOS = YSP/DIS
      ZNORTH = .FALSE.
      ZSOUTH = .FALSE.
C
C *** DETERMINE STARTING INDICES AND MAP SHEET BOUNDARIES   **
C
   10 IF(XS1 .LT. WEST) GO TO 560
      NX   = XS1-WEST
      YWEST = 0.0
      GO TO 570
  560 NX   = 0
      YWEST = YCOS*((WEST-XS1)/XSIN)
  570 IF (ABS(XSIN).LE.SRTWH) GO TO 1150
C
C ***    EAST   **
C
      IX   = NX
      X    = IX+WEST
      IDX  = 1
 1020 IX   = IX+IDX
      X    = X+RATE
      IF(IX .GT. MDIM) GO TO 2000
      R    = (X-XS1)/XSIN
      JY   = R*YCOS+YS1
      NAR  = (JY-1)/MDIM
      JY   = JY-NAR*MDIM
      NAR  = NAR+1
C
C *** TANGENT FOR ALL COMPASS DIRECTION       **
C *** IF NAR OUTSIDE MAP SHEET - LOS EXIST    **
C
 1075 IF((NAR .LT. SOUTH) .OR. (NAR .GT. NORTH)) GO TO 1800
      Z = IDATA(JY,IX,NAR)
      IF(ZCURVE) DZ=0.5*R*(R/RE)
      T = (Z-ZS1-DZ)/(R*ZGRID)
      IF(T .LE. TM) GO TO 1090
      GO TO 1900
 1090 IF(R .GE. RMAX) GO TO 1800
      IF(ZNORTH) GO TO 1130
```

```
      IF(ZSOUTH) GO TO 1135
      GO TO 1020
C
C ***   NORTH   ***
C
 1130 Y    = Y+DY
      JY   = JY+JDY
      IF(JY .LE. MDIM) GO TO 1140
      JY   = 1
      NAR  = NAR+1
      GO TO 1140
C
C ***   SOUTH   ***
C
 1135 Y    = Y+DY
      JY   = JY+JDY
      IF(JY .GE. 1) GO TO 1140
      JY   = MDIM
      NAR  = NAR-1
 1140 R    = (Y-YS1)/YCOS
      IX   = R*XSIN+XS1
      IF(IX .GT. MDIM) IX=IX-WEST+1
      IF(IX .GT. MDIM) GO TO 2000
      GO TO 1075
 1150 IF(YCOS .GT. 0.0) GO TO 1160
C
C ***   SOUTH   ***
C
      ZSOUTH = .TRUE.
      JY   = YS1+YWEST-RATE
      NAR  = (JY-1)/MDIM
      JY   = JY-NAR*MDIM
      NAR  = NAR+1
      Y    = YS1+YWEST-RATE
      DY   =-RATE
      JDY  =-1
      GO TO 1140
C
C ***   NORTH   ***
C
 1160 ZNORTH = .TRUE.
      JY   = YS1+YWEST
      NAR  = JY/MDIM
      JY   = JY+1-NAR*MDIM
      NAR  = NAR+1
      Y    = YS1+YWEST+RATE
      DY   = RATE
      JDY  = 1
      GO TO 1140
 1800 IF(LH .EQ. 2) GO TO 1850
      DETLO(LP) = DETLO(LP)+1.0
      DISLO(LP) = DISLO(LP)+DIS
```

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